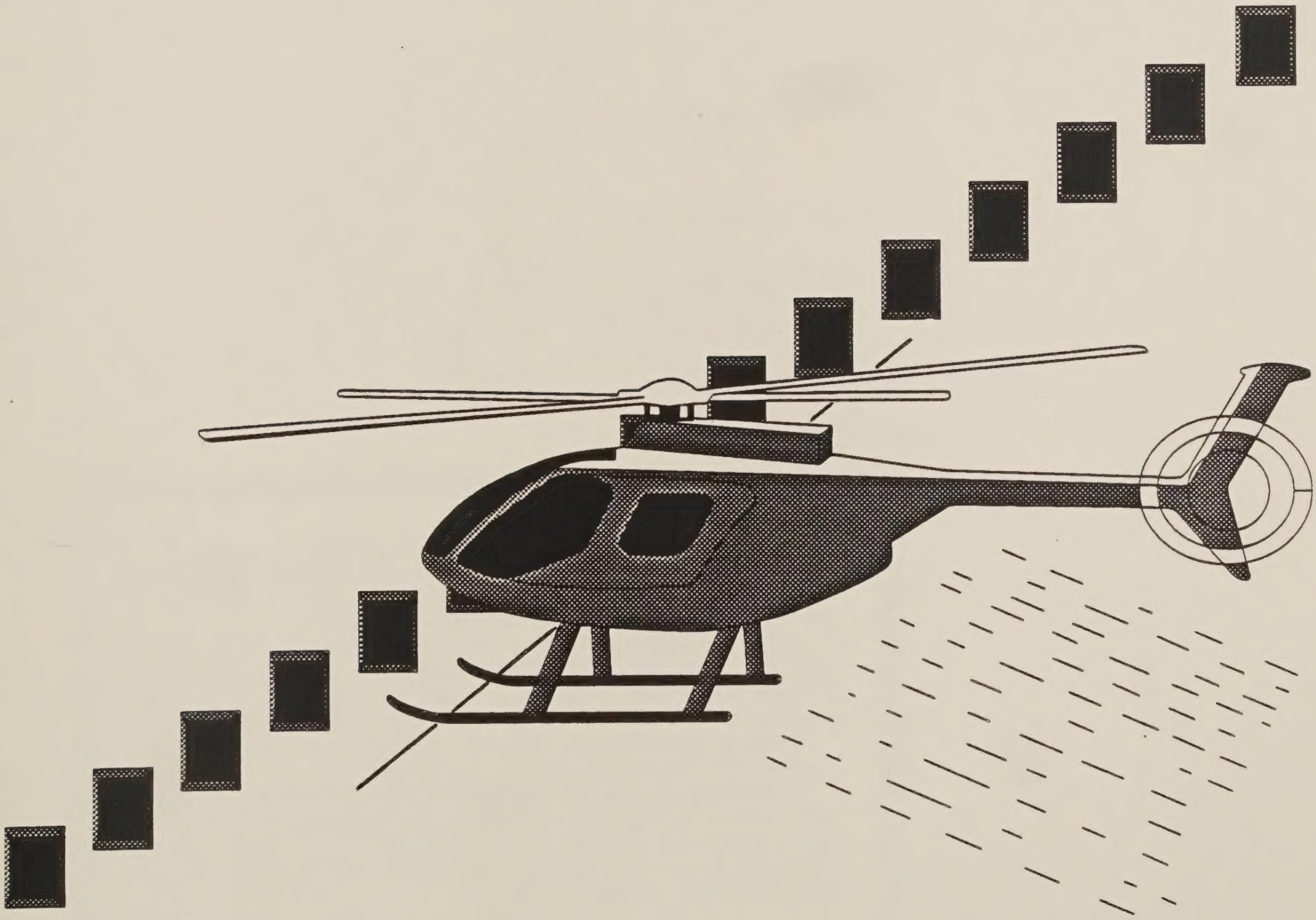
United States
Department of
Agriculture

Forest Service

Forest Pest
Management

Davis, CA

FSCBG MODEL COMPARISONS WITH THE 1991 DAVIS VIRUS SPRAY TRIALS



FPM 94-2
January 1994

Pesticides used improperly can be injurious to human beings, animals, and plants. Follow the directions and heed all precautions on labels. Store pesticides in original containers under lock and key—out of the reach of children and animals—and away from food and feed.

Apply pesticides so that they do not endanger humans, livestock, crops, beneficial insects, fish, and wildlife. Do not apply pesticides where there is danger of drift when honey bees or other pollinating insects are visiting plants, or in ways that may contaminate water or leave illegal residues.

Avoid prolonged inhalation of pesticide sprays or dusts; wear protective clothing and equipment, if specified on the label.

If your hands become contaminated with a pesticide, do not eat or drink until you have washed. In case a pesticide is swallowed or gets in the eyes, follow the first aid treatment given on the label, and get prompt medical attention. If a pesticide is spilled on your skin or clothing, remove clothing immediately and wash skin thoroughly.

NOTE: Some States have restrictions on the use of certain pesticides. Check your State and local regulations. Also, because registrations of pesticides are under constant review by the U.S Environmental Protection Agency, consult your local forest pathologist, county agriculture agent, or State extension specialist to be sure the intended use is still registered.

FPM 94-2
C. D. I. Technical Note No. 93-14
January 1994

FSCBG MODEL COMPARISONS WITH THE 1991 DAVIS VIRUS SPRAY TRIALS

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Summary

FSCBG simulations are presented for the aerial application of two virus formulations, TM Biocontrol and Gypchek, from two aircraft configured with two types of rotary atomizers and one type of hydraulic nozzle. Twenty-one trials were performed by the USDA Forest Service in January 1991 at a test site near Davis, California. Deposition variables determined during analysis of the field test data are compared to FSCBG simulations of ground deposition for each of the trials. Average correlation of FSCBG predictions to the field data is R^2=0.66 for drops and R^2=0.62 for mass. Correlation improves when drop size characteristics are defined over a greater range of drop sizes. Wind tunnel testing is recommended to extend the existing database to drops below 34 micrometers and to test formulations, application rates and application conditions consistently with field operations to avoid the approximations that must be made when performing FSCBG comparisons.

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1. Introduction

This paper is the third of a series of validation studies to be accomplished in 1993-1995 for the Forest Service Cramer-Barry-Grim (FSCBG) aerial spray model (Teske et al. 1993) and its near-wake Agricultural Dispersal (AGDISP) model (Bilanin et al. 1989). Recent field tests of several aerial spray pesticides have been performed with a variety of aircraft. Ground deposition data from each of these tests is available for comparison with FSCBG and AGDISP simulations. This paper is concerned with a test performed in January 1991 to observe the atomization of two virus formulations in two types of rotary atomizer and one type of hydraulic nozzle. Two aircraft were used in the trials. This paper follows the format of our previous reports (MacNichol and Teske 1993a and 1993b).

The USDA Forest Service in cooperation with the United States Army has developed FSCBG incorporating AGDISP as its near-wake model. FSCBG predicts the transport and behavior of pesticide sprays released from aircraft, influenced by the aircraft wake and local atmospheric conditions, through downwind drift and deposition to total accountancy and environmental fate. The AGDISP near-wake representation solves a Lagrangian system of equations for the position and position variance of material released from each nozzle on the aircraft. The FSCBG far-wake representation begins with the results of AGDISP at the top of a canopy or near the ground, and solves a Gaussian diffusion equation to recover ground deposition. FSCBG includes an analytic dispersion model for multiple line sources oriented in any direction to the wind, an evaporation model for volatile spray components, a canopy penetration model for forest canopy interception, and an accountancy model to recover environmental fate of released material.

Drop size distributions give the mass distribution of material as it is atomized by each nozzle. Drops containing volatile material (such as water) begin to evaporate immediately upon entering the atmosphere, with the local temperature, relative humidity and relative wind speed determining the evaporation rate. The presence of the aircraft wake (with its vortical structure) may move material to unanticipated locations. Ambient winds superimpose additional horizontal velocity vectors on the spray material. Canopy deposition removes spray material from the air and prevents nonvolatile components from reaching the ground. Every aspect of the spray process is affected by the size and significance of atmospheric and aircraft-generated turbulence.

Meteorological calculations generate the background wind speed, temperature and relative humidity profiles. Evaporation calculations track the time rate of decrease of drop size. Canopy calculations remove additional material through impaction on vegetation. Near-wake calculations follow the behavior of released spray near the aircraft, and when out of wake influence or at the top of the canopy, hand off to the dispersion calculations to predict the dosage, concentration and deposition at user-designated downwind locations.

Technical aspects of the FSCBG model are discussed in Teske et al. (1993). Previous comparisons with data include downslope drift in open terrain (Barry et al. 1993), a drift study over desert (Boyle et al. 1975), canopy penetration in Southern pine (Rafferty et al. 1982), open terrain and canopy penetration in Douglas-fir (Teske et al. 1991), eastern oak

(Anderson et al. 1992), and Gambel oak (Rafferty and Grim 1992), in addition to our two previous reports (MacNichol and Teske 1993a and 1993b).

The aircraft spray trials referred to in this paper took place from January 15 to January 17, 1991 at Growers Air Service, Woodland, California. The USDA Forest Service (FS), Forest Pest Management, performed twenty-one trials to determine characteristics of two virus formulations, TM Biocontrol and Gypchek, aerially sprayed through helicopter and fixed wing spray systems. Each trial consisted of one pass over parallel card lines. Test objectives included: the identification of problems associated with dispersal of TM Biocontrol and Gypchek through specific spray and handling systems; and measurement of deposit data specifically intended for comparison with AGDISP and FSCBG models.

Meteorological data from the trials were reported by Ekblad and Lassila (1991). Kromekote deposit cards were analyzed using the SwathKit analysis package and deposition data is summarized by McConnell (1991). Deposition data for each trial include drops per square centimeter and volume in ounces/acre (oz/ac). The trials were purposely conducted over a range of weather conditions to represent actual aerial spray operations.

2. Field Trials Summary

2.1 Spray Site

Figure 1 shows a diagram of the test site The trials were conducted at Growers Air Service, County Road 27, Woodland, California. Two spray deposit sample lines were set up parallel to each other at approximately 18m apart. These card lines were designated A and B. Lines were set in different radial positions as the test progressed. As wind direction changed, the card lines were repositioned in an attempt to obtain in-wind spray runs with a perpendicular spray line. Often, however, there was a one-quarter easterly component that extended deposition toward the west end of the card lines (P. Skyler, USDA Forest Service, private communication). Trials 1-1 and 1-2 were conducted with the card lines at 274/94 degrees (measured from North). Card lines were then repositioned as follows: trials 1-3 through 2-3, 240/60 degrees; trials 3-1 through 4-3, 235/55 degrees; trials 5-1 through 7-3, 360/180 degrees; and trials 8-1 through 8-3, 230/50 degrees.

Kromekote cards were positioned along the ground every 3.05m. For trials 1 and 2, card lines were 30 positions long (91.4m) and for the remaining trials the card lines were 40 positions long (122m).

2.2 Meteorology Measurements

Each trial consisted of one pass over parallel card lines A and B. The trials are numbered 1-1, 1-2, 1-3, 2-1, 2-2, 2-3, 3-1, etc. The last trial is 8-3. There is no trial 6. For each of the trials, meteorological conditions and spray variables are identical over both card lines for the purposes of FSCBG simulation; however, card lines A and B have different field test deposition profiles. Since card lines A and B are simulated by the same FSCBG run, each trial is referred to only once in the tables which follow even though later comparisons of deposition data are done with data from both card lines.

Figure 2 shows the position of two meteorological towers used to take readings of wind speed, wind direction, temperature and relative humidity using Event Model for Complex Terrain (EMCOT) weather stations (Ekblad and Lassila 1991). Met Station 1 was positioned north of the card lines and Met Station 2 was positioned at the west end of the card lines. Wind speed, direction and relative humidity data were taken from each tower at a height of 1.5 meters. Temperature was measured from the two towers at heights of 1.5 and 6.2 meters. Detailed meteorological data is given in Ekblad and Lassila (1991).

Table 1 summarizes the meteorological data for each trial. The trials were conducted over a wide range of weather conditions. Over three days of testing, relative humidity during field tests ranged from 43% to 99% and temperature ranged from 3.3 to 16.1 degrees Celsius. Table 1 also shows the average temperature, relative humidity and wind direction for the twenty-one trials. The relative standard deviation of these variables (defined as the ratio of standard deviation to the average) indicates a large degree of variability in the meteorological data across the entire test matrix.

The wind speed during the trials was generally low, exceeding 4m/s during only trials 2-1 and 2-2. Wind direction was generally perpendicular to the card lines, and within 40 degrees of the aircraft heading. Trials 4-3 and 5-3 were flown with a 63 and 46 degree difference (respectively) in the wind direction and aircraft heading. Trials 4-2, 3-2

and 3-3 were flown approximately perpendicular to the wind, which was blowing almost directly along the sampler lines.

Note that winds at the release (10.7 and 15.2 meters) may have been different from the 1.5-meter measurement shown in Table 1: for example, although 1.5-meter winds for a trials were measured as 360 degrees, winds at release height may have given the spray cloud a heading of 30 degrees or more (P. Skyler, private communication).

2.3 Spray Aircraft Configuration

The trials were conducted with two aircraft, an Ag-Cat Super B single engine airplane (Schweizer Aircraft Corporation) and a Hiller UH-12E helicopter. Two types of rotary atomizers and one type of hydraulic nozzle were used: the Beecomist 360A and Micronair AU5000 rotary atomizers; and the hydraulic flat fan 8006. The atomizers and nozzles were positioned on a boom located under the wing of the airplane or at the bottom of the helicopter fuselage, perpendicular to the fuselage centerline.

All trials conducted with the helicopter (1-1 through 2-3) used six Beecomist 360A atomizers, three on either side of the fuselage. Trials conducted with the airplane used Micronair atomizers and hydraulic flat fan nozzles. Trials 3-1 through 5-3 were conducted with eight Micronair AU5000 atomizers. Trial 7 was conducted with forty flat fan 8006 nozzles and trial 8 used fifty-six flat fan 8006 nozzles. Atomizer and nozzle positions for each configuration are shown in Table 2.

Table 3 shows the spray system variables for each trial.

2.4 Spray Characteristics

Aircraft altitude (spray release height) for all trials except trial 3 was 15.2m AGL (10.7m for trial 3) and speed varied from 22.4 to 55.0 m/s. Aircraft speed and heading are shown in Table 4.

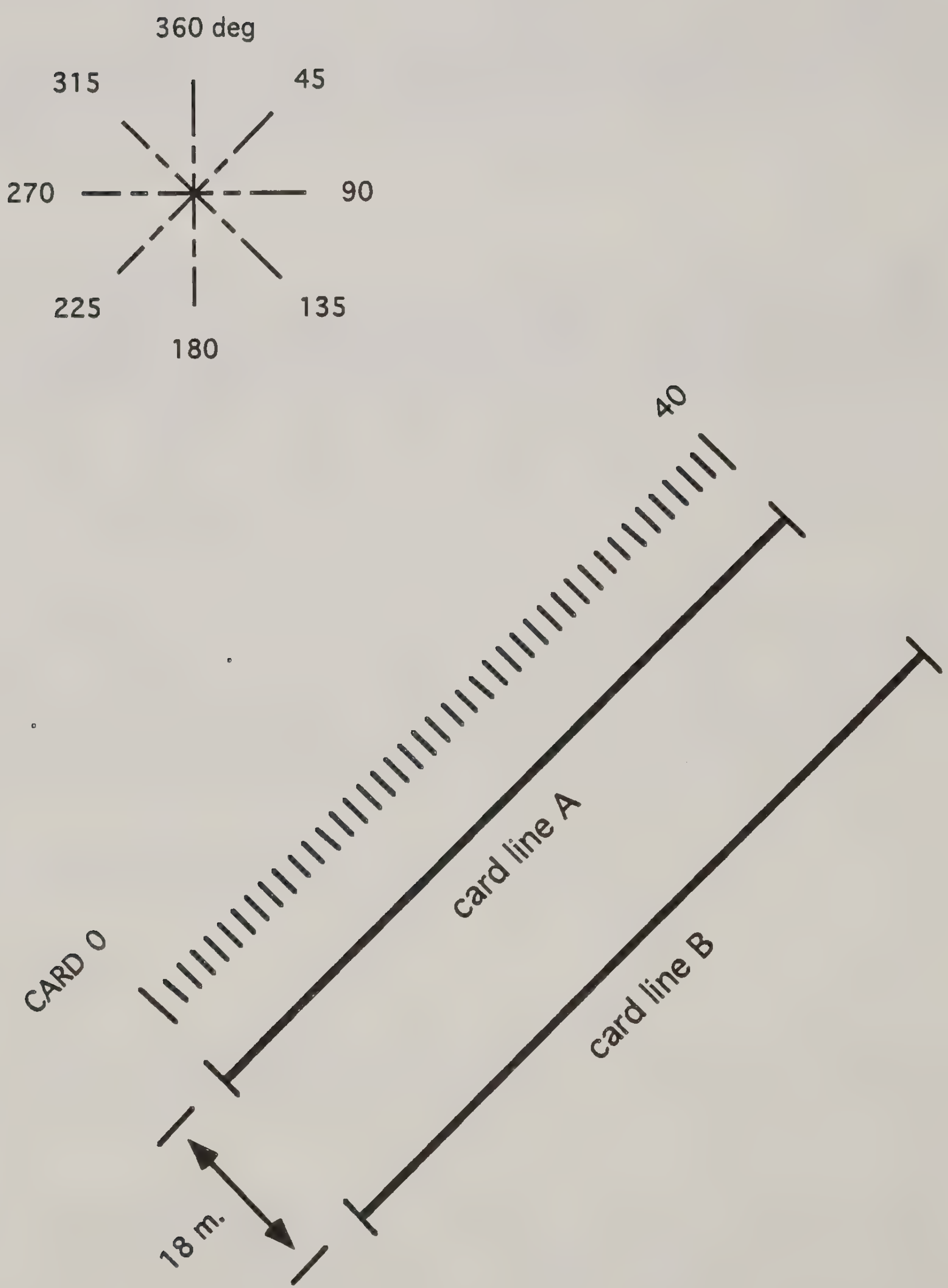
As previously mentioned, in each of the trials the aircraft flew over both card lines, A and B. The aircraft did not always fly directly into the wind (see section 2.2 and Table 3) and often did not fly over the center of the line. Offset from center generally was no more than 10 sampler positions (30m), but could be as high as 19 positions, or 58m (trial 7-3). The spray was turned on 177m before the card line.

TM Biocontrol and Gypchek virus formulations were sprayed at the application rates shown in Table 3. TM Biocontrol was sprayed at 21.1 and 42.0 l/min in the Beecomist atomizer, at 45.8 l/min in the Micronair atomizer and at 91.6 l/min in the flat fan nozzles. Gypchek was sprayed at 114.7 l/min in the Micronair atomizer and at 126.0 l/min in the flat fan nozzles. Note that Gypchek was sprayed at two rotation rates in the Micronair atomizer: trials 5-1 through 5-3 were at a higher rotation rate than trials 4-1 through 4-3. The drop size characteristics for each formulation are given in Table 5.

Spray deposit cards were assessed following the spray pass and analyzed with the SwathKit image analysis system; deposition data are summarized in McConnell (1991). Ground deposition data from each trial includes number of drops deposited per square centimeter and mass deposition in terms of volume per square centimeter, presented as ounces per acre. This data is the basis for comparison with FSCBG predictions of deposition.

2.5 Results

The present document is the first examination of the Davis virus spray trials and is based entirely on the field test data sheets (Skyler 1991), the SwathKit analysis package (McConnell 1991), and private communications with Forest Service personnel.



Card line length for trials 1-1 through 2-3: 91.4 m (30 cards)
Card line length for trials 3-1 through 8-3: 122 m (40 cards)

Cards were positioned radially as specified in section 2.1.

FIGURE 1: Test site at Growers Air Service.

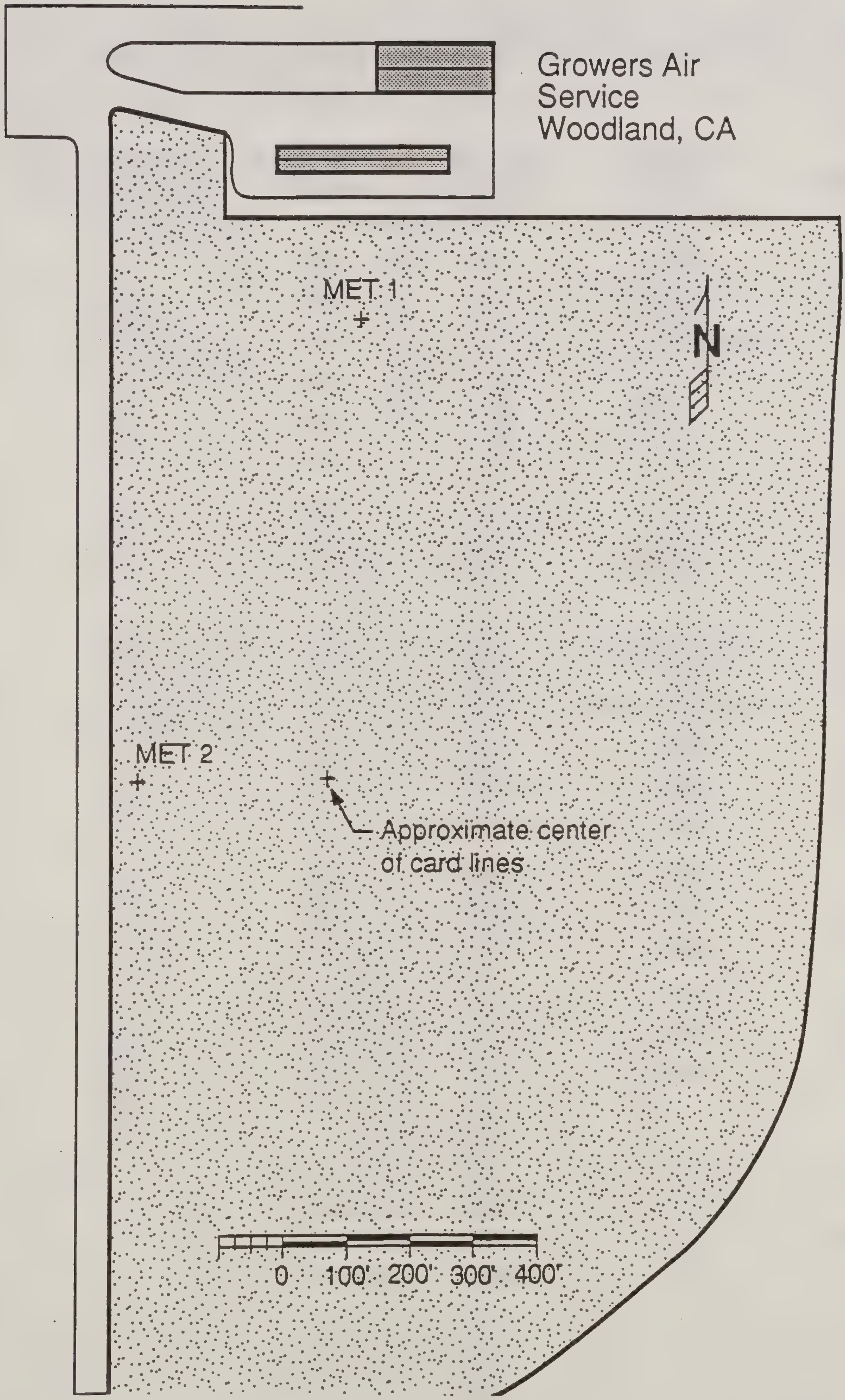


FIGURE 2: Placement of meteorological towers at Growers Air Service test site.

TABLE 1: Summary of meteorology data for the Davis virus spray trials.

Trial #	Temperature (deg C)	Relative Humidity (%)	Wind Speed (m/s)	Wind Direction (deg. from North)
1-1	10.6	90	3.6	2
1-2	10.6	90	2.9	333
1-3	10.6	88	3.6	348
2-1	11.1	84	4.7	328
2-2	11.1	83	5.1	335
2-3	11.1	82	3.4	328
3-1	3.9	97	0.2	24
3-2	3.9	96	2.2	71
3-3	4.4	95	2.4	73
4-1	10	58	2.8	21
4-2	10	60	2.3	62
4-3	10	60	2.2	48
5-1	10.6	59	2.5	55
5-2	10.6	58	1.9	58
5-3	11.1	56	2.4	44
7-1	3.3	99	2.0	235
7-2	3.9	98	2.4	239
7-3	3.9	98	1.8	236
8-1	16.1	43	3.9	153
8-2	16.1	44	3.6	152
8-3	15.6	44	4.0	143
Average:	9.45	75	2.8	
Relative standard deviation:	0.43	0.27	0.40	

TABLE 2: Atomizer or nozzle positions along the spray boom. Location is defined as positive to the pilot's right, with 0.0 at the aircraft centerline. Note that Micronair atomizers were used at three different speeds and with both formulations (8000 RPM with TM Biocontrol, 3000 and 6500 RPM with Gypchek), but were in the same positions throughout testing.

Configuration	Atomizer/nozzle location (m)		Configuration	Atomizer/nozzle location (m)	
	3.70			4.62	
Hiller UH-12E with Beecomist 360A	2.68		Ag-Cat Super B with Micronair AU5000	3.58	
	1.71			2.52	
	-1.76			1.45	
	-2.77			-1.58	
	-3.76			-2.64	
				-3.58	
				-4.65	
	4.42	-4.72		3.20	-3.50
	4.27	-4.57		3.05	-3.35
	4.12	-4.42		2.90	-3.20
Ag-Cat Super B with hydraulic flat fan 8006	3.96	-4.27	Ag-Cat Super B with hydraulic flat fan 8006	2.74	-3.05
	3.81	-4.12		2.59	-2.90
	3.66	-3.96		2.44	-2.74
	3.50	-3.81		2.29	-2.59
	3.35	-3.66		2.13	-2.44
	3.20	-3.50		1.98	-2.13
	3.05	-3.35		1.83	-1.98
	2.90	-3.20		1.68	-1.83
	2.74	-3.05		1.52	-1.68
	2.59	-2.90		1.37	-1.52
	2.44	-2.74		1.22	-1.37
	2.29	-2.59		1.07	-1.22
	2.13	-2.44		0.91	-1.07
	1.98	-2.13		0.76	-0.91
	1.83	-1.98		0.61	-0.61
	1.68	-1.83		0.45	-0.45
	1.52	-1.68		0.30	-0.30
	1.37	-1.52			
	1.22	-1.37			
	1.07	-1.22			
	0.91	-1.07			
	0.76	-0.91			
	0.61	-0.61			
	0.45	-0.45			
	0.30	-0.30			

TABLE 3: Spray system variables for the Davis virus spray trials. Rotary atomizers referred to are the Beecomist 360A and the Micronair AU5000. Flat fan refers to hydraulic flat fan 8006 nozzles. Atomizer and nozzle configurations are shown in Table 2.

Trial #	Formulation	Aircraft	Atomizer	Flow Rate (l/min)
1-1	TM BioControl	Hiller UH-12	Beecomist	21.2
1-2	TM BioControl	Hiller UH-12	Beecomist	21.2
1-3	TM BioControl	Hiller UH-12	Beecomist	21.2
2-1	TM BioControl	Hiller UH-12	Beecomist	42.0
2-2	TM BioControl	Hiller UH-12	Beecomist	42.0
2-3	TM BioControl	Hiller UH-12	Beecomist	42.0
3-1	TM BioControl	Ag-Cat	Micronair	45.8
3-2	TM BioControl	Ag-Cat	Micronair	45.8
3-3	TM BioControl	Ag-Cat	Micronair	45.8
4-1	Gypchek	Ag-Cat	Micronair	114.7
4-2	Gypchek	Ag-Cat	Micronair	114.7
4-3	Gypchek	Ag-Cat	Micronair	114.7
5-1	Gypchek	Ag-Cat	Micronair	114.7
5-2	Gypchek	Ag-Cat	Micronair	114.7
5-3	Gypchek	Ag-Cat	Micronair	114.7
7-1	TM BioControl	Ag-Cat	Flat fan	91.6
7-2	TM BioControl	Ag-Cat	Flat fan	91.6
7-3	TM BioControl	Ag-Cat	Flat fan	91.6
8-1	Gypchek	Ag-Cat	Flat fan	126.0
8-2	Gypchek	Ag-Cat	Flat fan	126.0
8-3	Gypchek	Ag-Cat	Flat fan	126.0

TABLE 4: Aircraft variables for the Davis virus spray trials.

Trial #	Aircraft heading (deg from N)	Aircraft Speed (m/s)
1-1	5	22.4
1-2	5	27.3
1-3	320	23.7
2-1	320	24.1
2-2	320	23.2
2-3	320	24.1
3-1	345	47.8
3-2	345	48.3
3-3	345	51.4
4-1	345	48.7
4-2	345	44.7
4-3	345	44.2
5-1	90	42.5
5-2	90	42.5
5-3	90	44.7
7-1	270	52.3
7-2	270	52.3
7-3	270	55.0
8-1	140	44.7
8-2	140	47.8
8-3	140	48.3

TABLE 5: Drop size characteristics for TM Biocontrol and Gypchek, given for the spray systems shown in Table 3 (Skyler and Barry 1991 for the drop size characteristics; for specific gravity and volatile fraction data, J. S. Hadfield, USDA Forest Service, private communication, for TM Biocontrol, and J. Podgwaite, USDA Forest Service, private communication, for Gypchek).

TM BioControl-1, Beecomist 360A

Specific Gravity = 1.10
Volatile Fraction = 0.697

Average Diameter (micrometers)	Mass Fraction
45.88	0.0721
73.78	0.1427
106.35	0.2746
138.62	0.3147
171.03	0.1186
203.42	0.0663
235.88	0.0072
268.32	0.0038

TM BioControl-1, Micronair AU5000

Specific Gravity = 1.10
Volatile Fraction = 0.697

Average Diameter (micrometers)	Mass Fraction
45.88	0.0028
73.78	0.0060
106.35	0.0181
138.62	0.0610
171.03	0.0960
203.42	0.1062
235.88	0.1140
268.32	0.1060
301.32	0.1178
334.77	0.0923
366.72	0.0794
398.21	0.0686
430.71	0.0377
463.18	0.0383
495.68	0.0178
528.67	0.0183
561.66	0.0112
594.65	0.0039
627.64	0.0034
660.64	0.0005
693.63	0.0006
726.63	0.0001

TABLE 5 (Cont'd): Drop size characteristics for TM Biocontrol and Gypchek, given for the spray systems shown in Table 3 (Skyler and Barry 1991 for the drop size characteristics; for specific gravity and volatile fraction data, J. S. Hadfield, USDA Forest Service, private communication, for TM Biocontrol, and J. Podgwaite, USDA Forest Service, private communication, for Gypchek).

Gypchek, Micronair AU5000 at 2700 RPM

Specific Gravity = 1.10
Volatile Fraction = 0.795

Average Diameter (micrometers)	Mass Fraction
45.88	0.0047
73.78	0.0091
106.35	0.0248
138.62	0.0623
171.03	0.0892
203.42	0.1061
235.88	0.1241
268.32	0.1378
301.32	0.1287
334.77	0.1036
366.72	0.0641
398.21	0.0482
430.71	0.0289
463.18	0.0206
495.68	0.0279
528.67	0.0086
561.66	0.0103
594.65	0.0049
627.64	0.0056
660.64	0.0004
693.63	0.0001

Gypchek, Micronair AU5000 at 7000 RPM

Specific Gravity = 1.10
Volatile Fraction = 0.795

Average Diameter (micrometers)	Mass Fraction
45.88	0.0129
73.78	0.0213
106.35	0.0818
138.62	0.2098
171.03	0.2579
203.42	0.1848
235.88	0.1190
268.32	0.0668
301.32	0.0282
334.77	0.0103
366.72	0.0030
398.21	0.0008
430.71	0.0025
463.18	0.0009

TABLE 5 (Cont'd): Drop size characteristics for TM Biocontrol and Gypchek, given for the spray systems shown in Table 3 (Skyler and Barry 1991 for the drop size characteristics; for specific gravity and volatile fraction data, J. S. Hadfield, USDA Forest Service, private communication, for TM Biocontrol, and J. Podgwaite, USDA Forest Service, private communication, for Gypchek).

TM BioControl-1, Flat Fan 8010

Specific Gravity = 1.10
Volatile Fraction = 0.697

Average Diameter (micrometers)	Mass Fraction
45.88	0.0116
73.78	0.0202
106.35	0.0495
138.62	0.1023
171.03	0.1472
203.42	0.1654
235.88	0.1797
268.32	0.1376
301.32	0.0646
334.77	0.0534
366.72	0.0273
398.21	0.0250
430.71	0.0064
463.18	0.0020
495.68	0.0074
528.67	0.0004

Gypchek, Flat fan 8006

Specific Gravity = 1.10
Volatile Fraction = 0.795

Average Diameter (micrometers)	Mass Fraction
45.88	0.0038
73.78	0.0073
106.35	0.0237
138.62	0.0572
171.03	0.0750
203.42	0.0781
235.88	0.0766
268.32	0.0871
301.32	0.0869
334.77	0.0731
366.72	0.0746
398.21	0.0628
430.71	0.0631
463.18	0.0551
495.68	0.0459
528.67	0.0393
561.66	0.0345
594.65	0.0239
627.64	0.0218
660.64	0.0084
693.63	0.0012
726.63	0.0006

3. FSCBG Simulation of Field Test Data

The objective of this report is to compare FSCBG predictions of deposition with the field test deposition data cited. A detailed description of input parameters necessary for FSCBG modeling may be found in Teske and Curbishley (1991).

Spray application rate, aircraft speed and heading, wind speed, relative humidity and temperature vary for each trial according to the field test data as previously shown in Tables 1, 3 and 4.

Aircraft configuration and powerplant data required by FSCBG are summarized in Table 6. FSCBG version 4.3 includes Ag-Cat Super B and Hiller UH-12E modules in its library of standard aircraft configurations. Configuration of rotary atomizers or hydraulic nozzles along the boom is as illustrated in Table 2.

Drop size characteristics used to generate FSCBG predictions of deposition for the two Bt formulations are as shown in Table 5. There were six combinations of formulation and spray system tested during the Davis virus spray trials. TM BioControl-1 was tested using a Beecomist 360A atomizer, a Micronair AU5000 atomizer and hydraulic flat fan 8006 nozzles. Gypchek was tested using a Micronair AU5000 atomizer at two different rotation rates, 3000 RPM and 6500 RPM, and was also tested using hydraulic flat fan 8006 nozzles. The FSCBG version 4.3 standard drop size library includes only one of the six combinations (Gypchek in the hydraulic flat fan 8006 nozzles). All other drop size characteristics used in FSCBG simulations of this field test are not exactly representative of the actual spray systems used during the test. Table 7 summarizes the spray systems used during the Davis virus trials and compares them to the spray systems assumed in FSCBG to simulate the trials.

TABLE 6: Aircraft characteristics for the Ag-Cat Super B and the Hiller UH-12E.

Aircraft	Ag-Cat Super B
Type	Fixed-wing biplane
Weight	3180.00 kg
Wing span	10.80 m
Planform area	37.25 m sq
Drag coefficient	0.10
Propeller radius	1.35 m
Propeller efficiency	0.85
Blade RPM	2300.00

Aircraft	Hiller UH-12E
Type	Helicopter
Weight	1406.00 kg
Rotor diameter	10.80 m
Blade RPM	394.00

TABLE 7: Spray systems in use during each trial and the spray systems used to model them in FSCBG. Note that for rotary atomizers, RPM refers to the rotation rate and degrees refers to the blade angle (rotation rate is determined by the blade angle setting). For hydraulic nozzles, degrees refers to the nozzle setting, where 0 degrees is straight back. Aircraft speed is given in mph.

Trial #	Actual spray system used in field testing	Spray system used for FSCBG simulation of field tests
1-1		
1-2	Beecomist 360A rotary atomizer	Beecomist 360A rotary atomizer
1-3	(aircraft speed 55 mph)	7600 RPM, 55 mph
2-1	spraying TM BioControl-1	spraying TM BioControl-1
2-2		
2-3		
3-1	Micronair AU5000 rot atomizer	Micronair AU5000 rot atomizer
3-2	8000 RPM, 45 degrees, 120 mph	11000 RPM, 135 mph
3-3	spraying TM BioControl-1	spraying TM BioControl-1
4-1	Micronair AU5000 rot atomizer	Micronair AU5000 rot atomizer
4-2	3000 RPM, 65 degrees, 100 mph	2700 RPM, 75 mph
4-3	spraying Gypchek	spraying Gypchek
5-1	Micronair AU5000 rot atomizer	Micronair AU5000 rot atomizer
5-2	6500 RPM, 35 degrees, 100 mph	7000 RPM, 75 mph
5-3	spraying Gypchek	spraying Gypchek
7-1	Flat fan 8006	Flat fan 8010
7-2	90 degrees, 120 mph	90 degrees, 135 mph
7-3	spraying TM BioControl-1	spraying TM BioControl-1
8-1	Flat fan 8006	Flat fan 8006
8-2	45 degrees, 110 mph	45 degrees, 110 mph
8-3	spraying Gypchek	spraying Gypchek

4. Results and Discussion

Comparison plots of field test deposition data and FSCBG deposition predictions for each of the twenty-one virus spray trials are presented in the Appendix. Deposition variables examined are drops per square centimeter and volume per square centimeter, given as ounces per acre (oz/ac). As previously mentioned, each trial in the field test consisted of a spray run over two parallel card lines; meteorological conditions and spray variables were identical for both card lines but different depositions were recorded on each card line. Thus, two sets of deposition data (labeled A and B) exist for each trial. FSCBG simulations are plotted as solid lines and field test data are plotted as open circles for card line A and open squares for card line B. Note that, although conducted under identical conditions, the two card lines in each trial do not show identical patterns of deposition.

Each of the comparison plots is briefly evaluated below. FSCBG predictions were adjusted to account for two factors: orientation of the field test deposition data and position of the aircraft over the test circle.

FSCBG generates deposition data along a line perpendicular to the aircraft flight path; this line is not always oriented along the field test sampler line. For example, in trial 3-1, the aircraft heading was 345 degrees and the sampler line was positioned at 235/55 degrees; the card line was 20 degrees off of the perpendicular to the flight path. When necessary, FSCBG predictions are adjusted to the orientation of the sampler card line.

As previously mentioned, the aircraft did not always fly over the center of the card line. In some of the trials the field test data sheets (Skyler, 1991) also indicate that cards were collected in reverse order (positions 0 and 40 were switched). FSCBG simulations are adjusted accordingly.

Qualitatively, the FSCBG model predictions do a very good job of simulating ground deposition for most of the Davis virus trials. The quantitative measure of correlation coefficient reduces the comparison to a single number, which may not entirely reflect the quality of the prediction.

Table 8 contains the correlation coefficients comparing the field test data (drops per square centimeter and ounces per acre) with FSCBG predictions. This table gives a quick summary of the test results and corresponding FSCBG predictions. For each trial, correlation coefficients (R^2 for drops and R^2 for mass) were calculated as follows: correlation of each card line (A and B) with FSCBG predictions was analyzed separately, then the correlation coefficients for card line A and card line B were averaged. The average correlation appears in Table 8.

Correlation coefficients for trial 1-2 are not included in the table because the amount of material deposited was very small, less than 10 drops per square centimeter for all but one card position and less than 5 drops per square centimeter for almost half the measured card positions. Predicted mass deposition was fairly accurate, but the deposition pattern was not predicted well.

The average correlation for the remaining trials is R^2=0.66 for drops and R^2=0.62 for mass, with most values above R^2=0.40 and a peak value of R^2=0.94 for drops and

R^2=0.90 for mass. Trials 4-1 through 4-3, conducted with Gypchek in Micronair atomizers, show the best correlation, with an average of R^2=0.83 for drops and R^2=0.87 for mass. Average correlation for the trials by formulation is: Gypchek, R^2=0.62 for drops and R^2=0.73 for mass; and TM BioControl-1, R^2=0.68 for drops and R^2=0.54 for mass.

The trials from this field test fall into three clear meteorological categories: trials 1-1 through 3-3 and 7-1 through 7-3 were all conducted in conditions of very high relative humidity and low to moderate temperatures, indicating little evaporation; trials 4-1 through 5-3 were done in moderate relative humidity and moderate temperatures, indicating moderate evaporation; and trials 8-1 through 8-3 were conducted in low relative humidity and moderate temperature, indicating fairly high evaporation. The latter trials, 8-1 through 8-3, were done with Gypchek in flat fan 8006 nozzles. Average correlation for these trials is R^2=0.53 for drops and R^2=0.75 for mass. Note that the correlation for drops is worse than the average correlation for drops of all the trials, even though the drop size characteristics used in FSCBG to model this set of trials are correct for the actual spray system used in the field test. Thus, although FSCBG predicts the mass deposition of these Gypchek trials well, there was apparently less evaporation during the field test than is indicated by FSCBG. Since meteorological conditions were favorable to a high rate of evaporation, a discrepancy in the volatile fraction used for FSCBG modeling of the Gypchek trials would be especially noticeable in these three trials.

Table 9 compares the volume median diameter (VMD) of droplets as listed on the SwathKit field results (McConnell, 1991) to the average VMD as calculated by FSCBG. The VMD associated with the drop size characteristics used in each trial is also given. This is the VMD of droplets as they emerge from the atomizer or nozzle. The rate of evaporation indicated by existing conditions of relative humidity and temperature is summarized as: low, moderate, and high. As previously indicated, the VMD calculated by FSCBG depends on the rate of evaporation and the volatile fraction of the formulation being sprayed. Thus, the VMD at deposition is some percentage of the VMD at atomization. Table 9 indicates that for some of the trials (4-1 through 7-3), the mass at atomization was not adequately represented by the drop size characteristics chosen to model the trials. Although this discrepancy did not noticeably affect trials 4-1 through 4-3, trials 5-1 through 7-3 show the poorest overall correlation for drops and mass (average R2=0.58 for drops and R2=0.45 for mass). VMD values calculated by FSCBG for the remaining trials (1-1 through 3-3 and 8-1 through 8-3) all fall below the actual VMD readings in the field test.

The six sets of drop size characteristics used to model the virus spray trials are defined to differing degrees of detail (see Table 5). Characteristics used to model trials 1-1 through 2-3, 4-1 through 4-3 and 8-1 through 8-3 are all defined from an average diameter of 46 micrometers to at least 693 micrometers. The remaining trials use drop size characteristics which are defined to 268 (trials 3-1 through 3-3), 463 (5-1 through 5-3) and 528 (7-1 through 7-3) micrometers. As mentioned previously, trials 5-1 through 7-3 show the poorest correlation for both drops and mass; although trial 3-2 shows excellent correlation (R2=0.94 for drops and R2=0.88 for mass), trials 3-1 and 3-3 do not correlate as well.

It should be noted that in our previous papers (MacNichol and Teske 1993a and 1993b) the importance of accurate modeling of drop size characteristics was stressed. A recommendation was made to extend the existing database of drop size characteristics to include drops below 34 micrometers (MacNichol and Teske 1993b). Several of the trials

in this analysis show good correlation for mass, but poor correlation for drops, indicating that the smaller droplets are not being adequately modeled in FSCBG. Trials 5-3 and 8-2 are striking examples of this problem: in both trials, correlation for mass is approximately R^2=0.70, yet correlation for drops is just R^2=0.10 (trial 5-3) and R^2=0.23 (trial 8-2). It is the authors' opinion that more consistent modeling results would be obtained if the drop size characteristics database was also defined in greater detail (drop size characteristics are currently given in increments of approximately 32 micrometers). Although existing data could be extrapolated to achieve smaller increments, the resulting drop size spectra might not be truly representative of the atomization pattern desired.

TABLE 8: Correlation coefficients for trials 1-1 through 8-3 comparing field data and FSCBG predictions for drops and mass deposited. Trials with correlation coefficients above 0.50 are considered "good."

Trial #	Correlation to drops	Correlation to mass	Comments
1-1	0.78	0.67	Good comparison.
1-2	---	---	Small amount of mass deposited (see Section 4).
1-3	0.65	0.62	Good comparison.
2-1	0.68	0.35	Good comparison.
2-2	0.66	0.64	Good comparison.
2-3	0.56	0.69	Very good comparison.
3-1	0.66	0.42	Good comparison.
3-2	0.94	0.88	Very good comparison.
3-3	0.62	0.59	Good comparison.
4-1	0.86	0.86	Good comparison.
4-2	0.76	0.90	Very good comparison.
4-3	0.86	0.85	Good comparison.
5-1	0.72	0.57	Good comparison.
5-2	0.74	0.41	Good comparison.
5-3	0.10	0.70	Good comparison.
7-1	0.65	0.00	Good comparison of drops.
7-2	0.74	0.60	Good comparison.
7-3	0.54	0.43	Peak deposition of mass under predicted.
8-1	0.50	0.76	Good comparison of mass.
8-2	0.23	0.69	Deposition profile of drops under predicted.
8-3	0.85	0.81	Good comparison.
Average	0.66	0.62	

TABLE 9: Volume Median Diameter (VMD) for the Davis Virus Spray Trials: field test measurements; VMD at atomization (as given in drop size characteristics); and VMD at deposition as predicted by FSCBG, averaged for each set of trials. Evaporation refers to the evaporation rate indicated by meteorological conditions during the trial: low (at least 70% of the spray material deposited); moderate (50-70% of spray material deposited); and high (less than 50% of material deposited). All VMD values are given in micrometers.

Trial #	Field test VMD	VMD at atomization	VMD at deposition (FSCBG)	Evaporation
1-1	191			low
1-2	214	281	202	low
1-3	241			low
2-1	289			low
2-2	302	281	197	low
2-3	258			low
3-1	128			low
3-2	123	123	100	low
3-3	109			low
4-1	300			moderate
4-2	308	271	180	moderate
4-3	304			moderate
5-1	178			moderate
5-2	166	176	115	moderate
5-3	194			moderate
7-1	385			low
7-2	210	220	182	low
7-3	220			low
8-1	204			high
8-2	172	320	133	high
8-3	176			high

5. Conclusions

FSCBG predictions of the Davis Virus Spray Trials ground deposition data show good correlation, with an overall R^2=0.66 for drops and R^2=0.62 for mass. These values are well above the acceptable level for operational field tests. However, predicted deposition would probably have been even better if exact drop size characteristics had been available for FSCBG modeling.

Drop size characteristics were available for only one of the six combinations of formulation and atomizer or nozzle type used in these trials (Gypchek in a hydraulic flat fan 8006 nozzle). Drop size characteristics used for the other five combinations were not exactly representative of the actual spray systems used. Whenever the drop size distributions used in FSCBG were defined over a large range of drop diameters, the average correlation for drops and mass improved.

In addition, the volatile fraction data supplied for the two virus formulations used may not be accurate for the formulations in use during the field test. Since some of the trials occurred in conditions favorable to high evaporation (low relative humdity and high temperature), the active fraction of the formulations is a critical parameter. Thus, the correlation of predicted deposition to field test data is relatively poor for those trials which occurred in conditions of moderate and high evaporation and is also relatively poor for trials in which drop size data is not adequately defined.

A wind tunnel test of formulations, nozzle and atomizer types that are currently in use by the USDA Forest Service is suggested in order to expand the existing database of drop size characteristics available to FSCBG users. It should be noted that merely duplicating the formulation and nozzle type is not sufficient; drop size characteristics are dependent on all spray system variables, including nozzle angle setting for hydraulic nozzles, atomizer rotation rate for rotary atomizers, and aircraft speed. If any of these parameters is not exactly represented, then the drop size characteristics used to model a trial are not entirely correct.

Furthermore, the existing database should be extended to drops below 34 micrometers and defined in smaller increments. Extrapolation of existing data may generate distributions that will not accurately represent the shape of the drop distribution.

6. Field Test Recommendations

FSCBG performed very well against the 1991 Davis Virus Spray Trials. However, several limitations have been noted which had a direct impact on the accuracy of the modeling of the trials:

1. Only the most basic meteorological measurements were made.

2. Volatility and specific gravity of the formulations were not ascertained at the time of the trials.

3. Drop size distributions were assumed for most of the trials simulated.

Average correlation for the Davis Virus Spray Trials of R^2=0.66 for drops and R^2=0.62 for mass shows that, as previously demonstrated by the authors (MacNichol and Teske 1993b), FSCBG may be exercised when only approximate information is available, with some confidence in its predictions. In the best of all worlds (with no regard for the cost involved), FSCBG comparisons would be greatly enhanced with the following test plan additions:

1. Meteorological data should include three accurate measurements of wind speed and direction (at three heights, up to the spray release height if possible), to extract the boundary layer profile and provide an accurate reading of the wind direction.

2. An accurate measure of spray release height, one of the most critical field parameters (Teske and Barry 1993).

3. Wind tunnel atomization of the spray material in the exact spray system used in the field test.

4. Volatility determination of the spray materials actually in use at the test site. Material from the tank mix should be removed at the test site and sent to a lab for determination of the active fraction.

5. Accurate measurement of the specific gravity of the spray materials in use at the test site.

6. Timely interpretation of the witness cards, to avoid contamination and degradation over time. No details regarding collection of sampler cards was available for these trials.

7. Acknowledgment

These trials were made possible through the cooperation of Growers Air Service and the following Forest Service offices: Missoula Technology and Development Center; Northeast Area (Appalachian Integrated Pest Management); Pacific Northwest Region (Forest Pest Management); Pacific Northwest Station (Forestry Sciences Lab); and Washington Office (Forest Pest Management, Davis, CA). We especially recognize the support provided by Russ Stocker, Jim Hadfield, Tim McConnell, Dick Reardon, Pat Skyler, Roy Beckwith, Dave Grimble and Don Lasilla.

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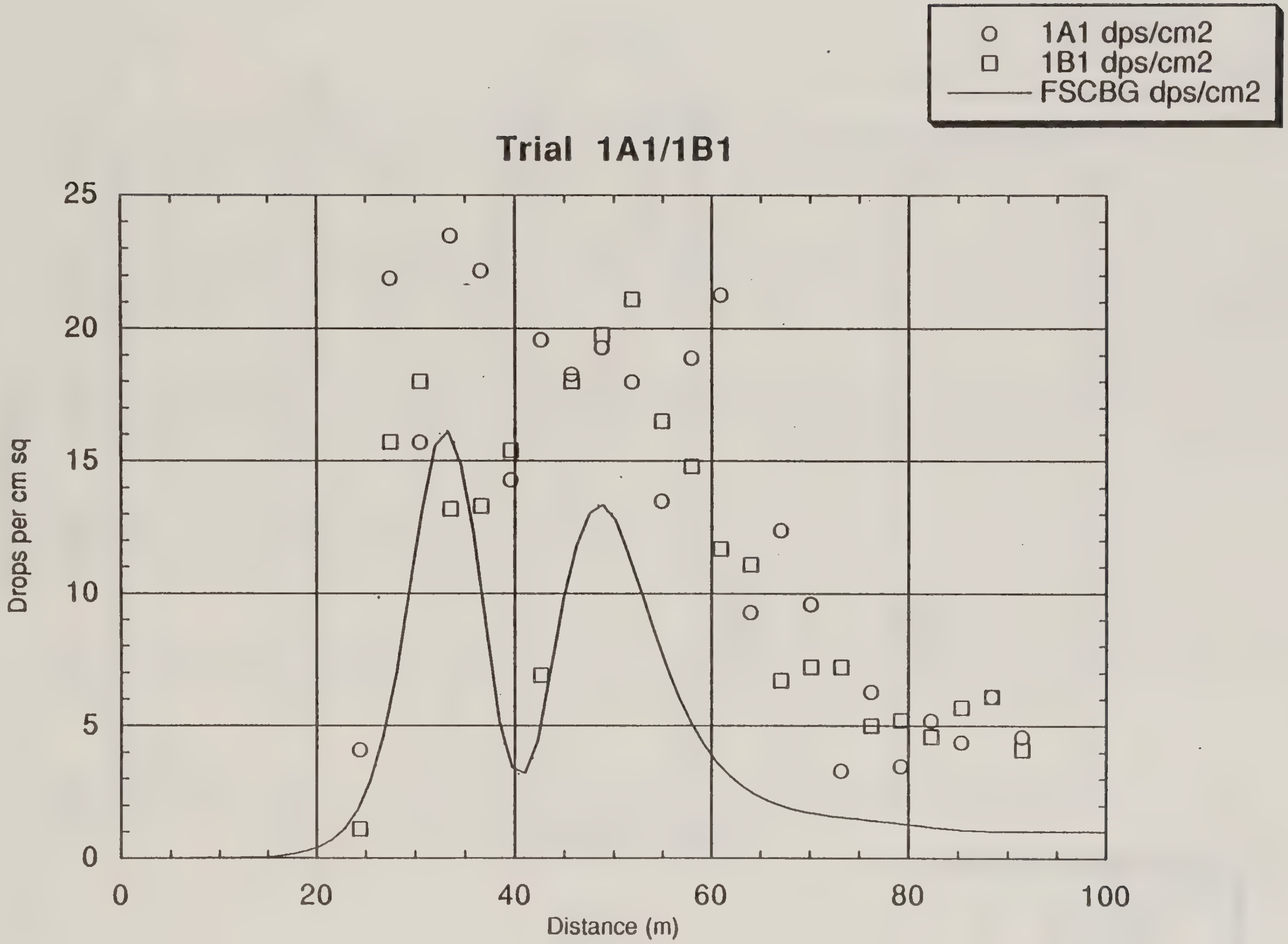
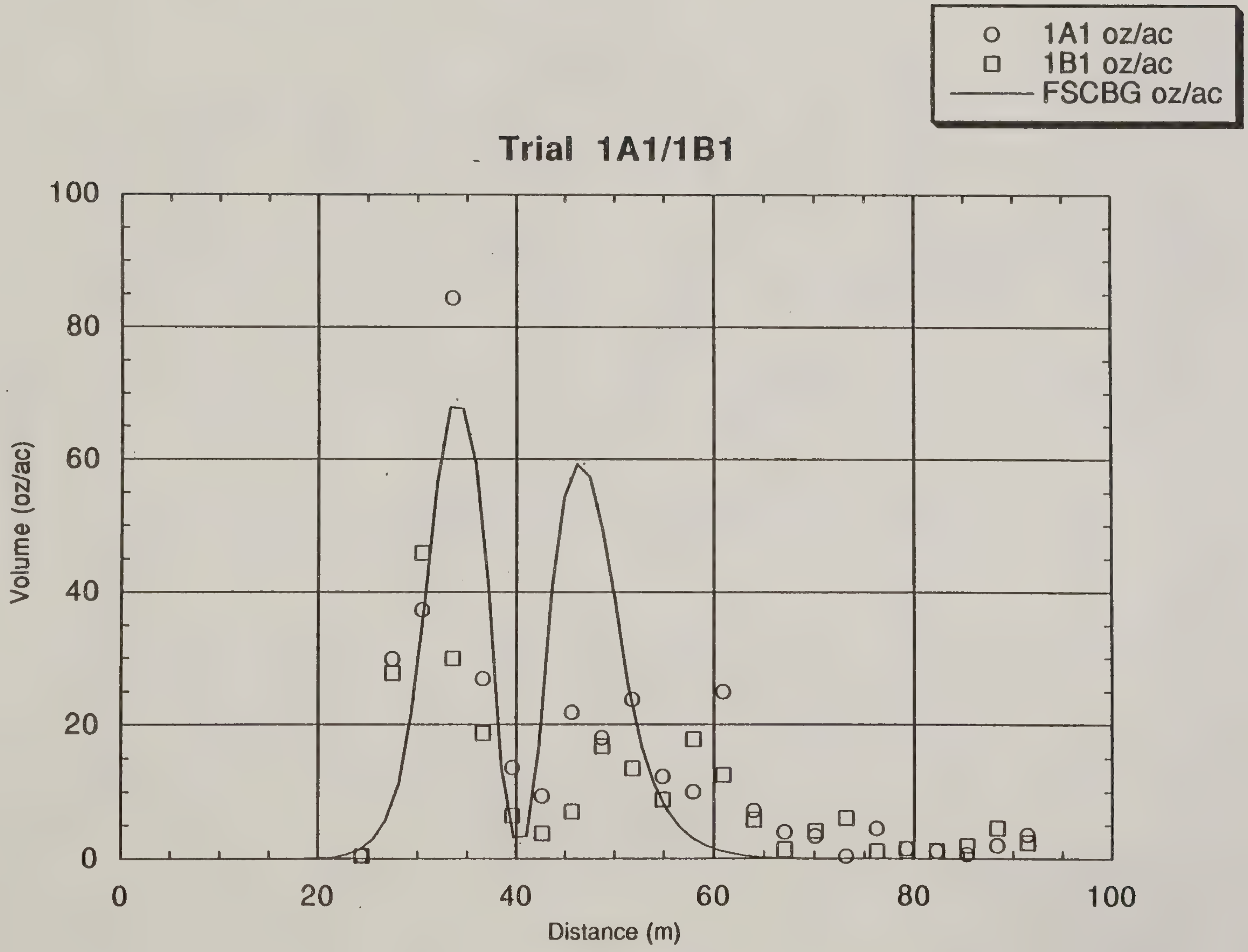
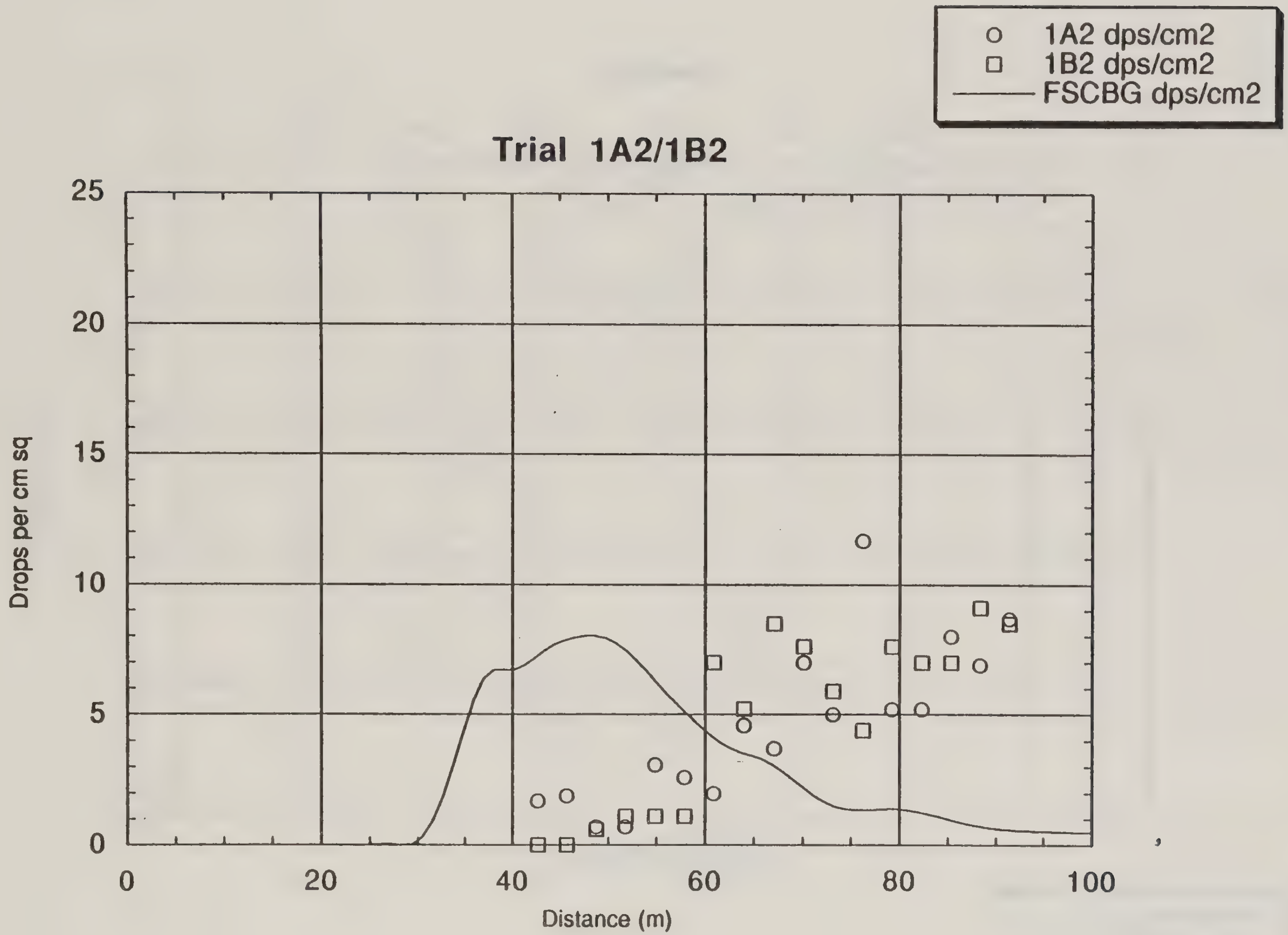
Appendix

The Appendix contains a plot of drops per square centimeter and volume per square centimeter (in ounces per acre, oz/ac) for each of the twenty-one Davis Virus Spray Trials (1-1 through 8-3, with no trial 6). Each trial consists of two sets of field card lines, A and B. Data is shown as open circles for card line A and open squares for card line B; FSCBG predictions as solid lines.


Trial 1A1/1B1
1A1 dps/cm2
1B1 dps/cm2
FSCBG dps/cm2
Drops per cm sq
Distance (m)
0
5
10
15
20
25
0
20
40
60
80
100



1A1 oz/ac
1B1 oz/ac
FSCBG oz/ac
Trial 1A1/1B1
Volume (oz/ac)
Distance (m)
0
20
40
60
80
100


1A2 dps/cm2
1B2 dps/cm2
FSCBG dps/cm2
Trial 1A2/1B2
Drops per cm sq
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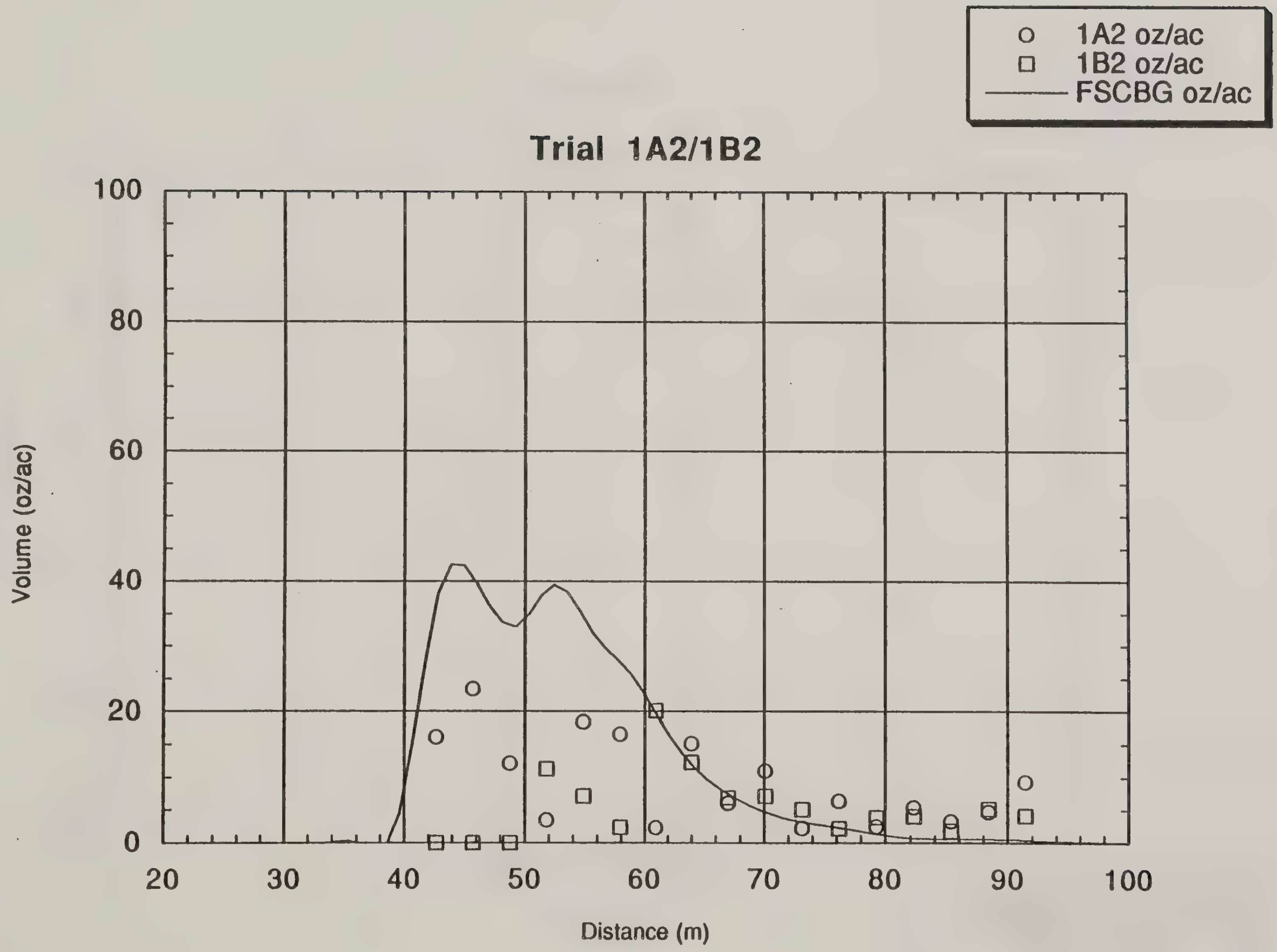
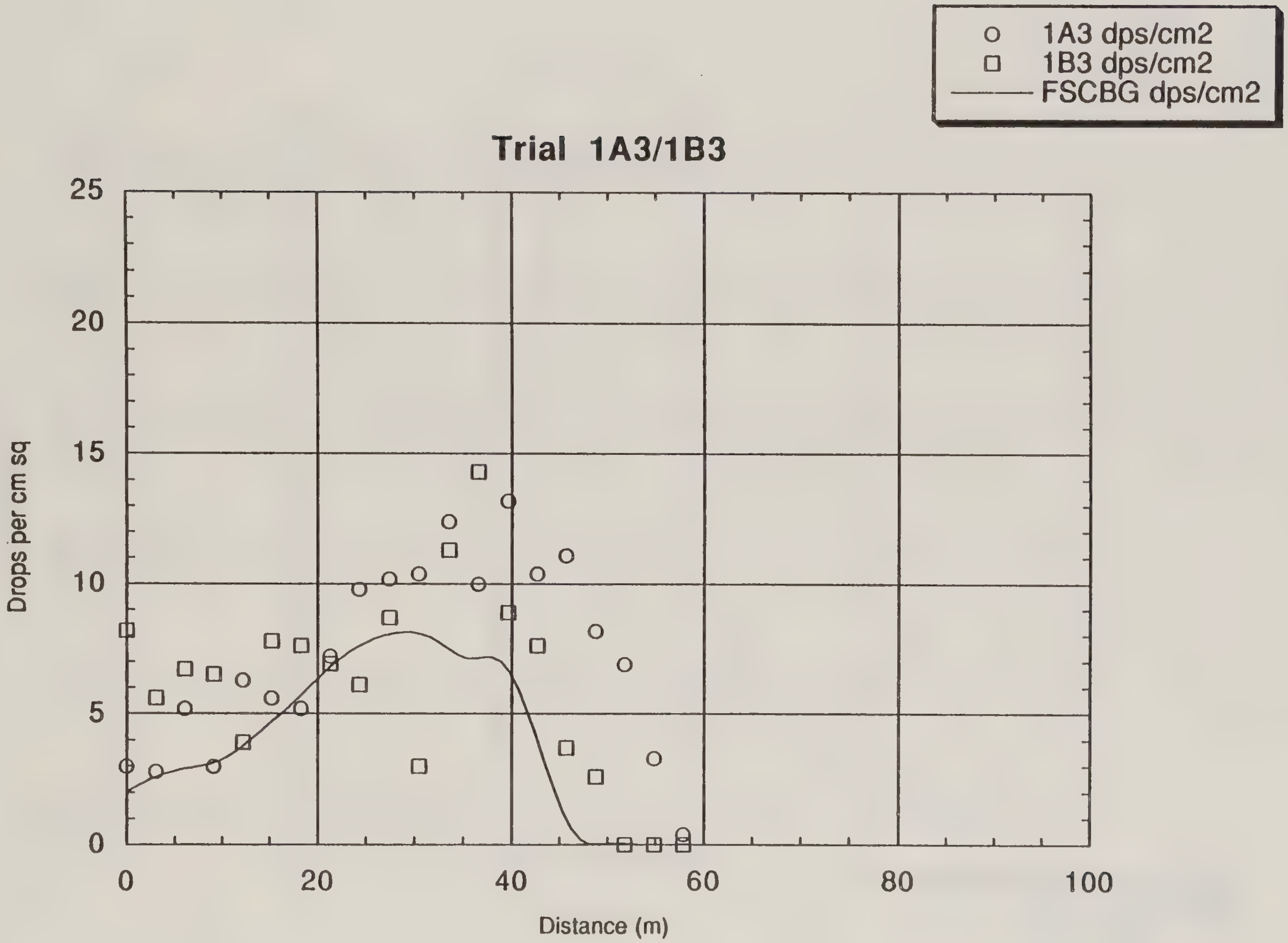
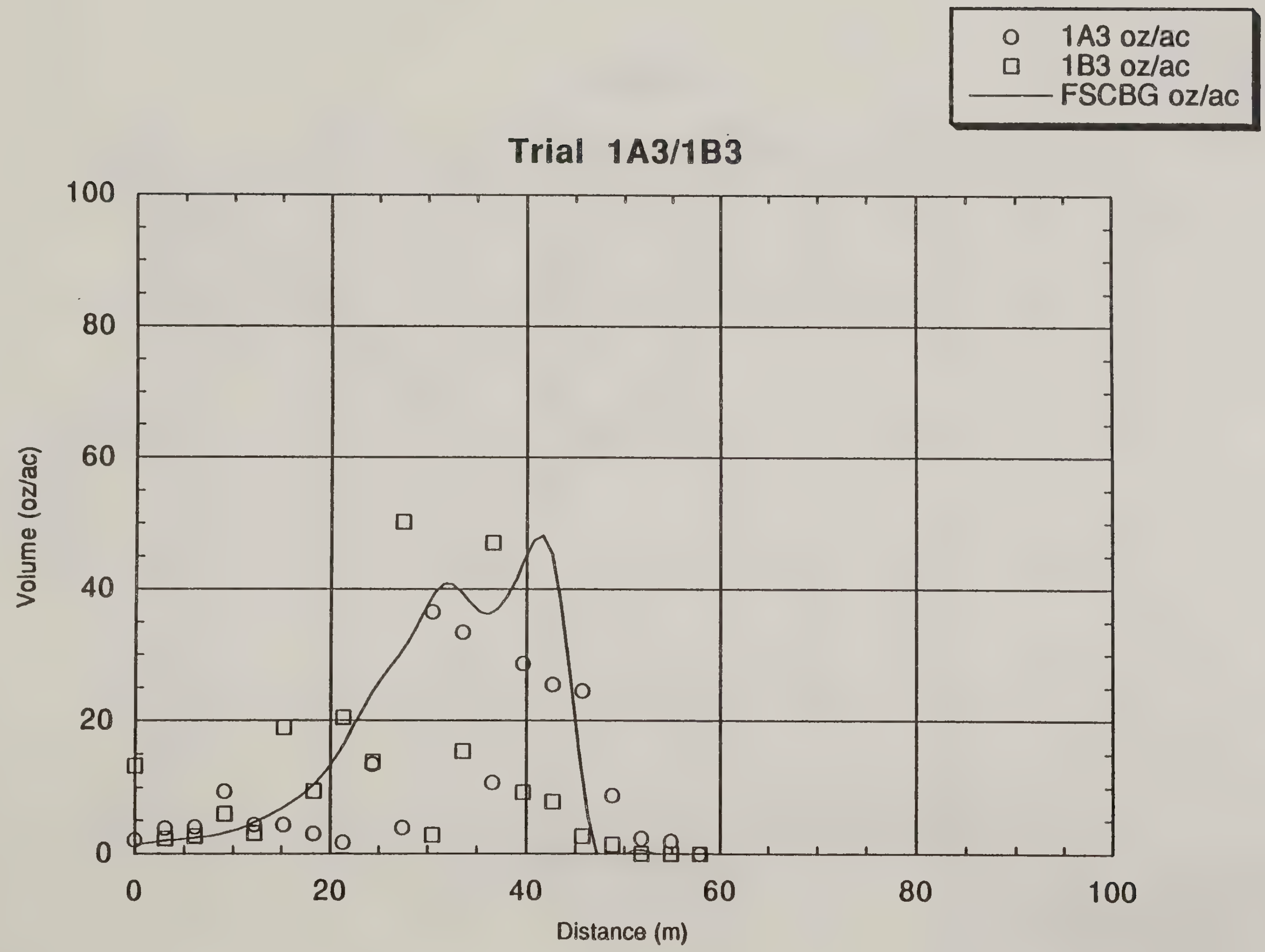
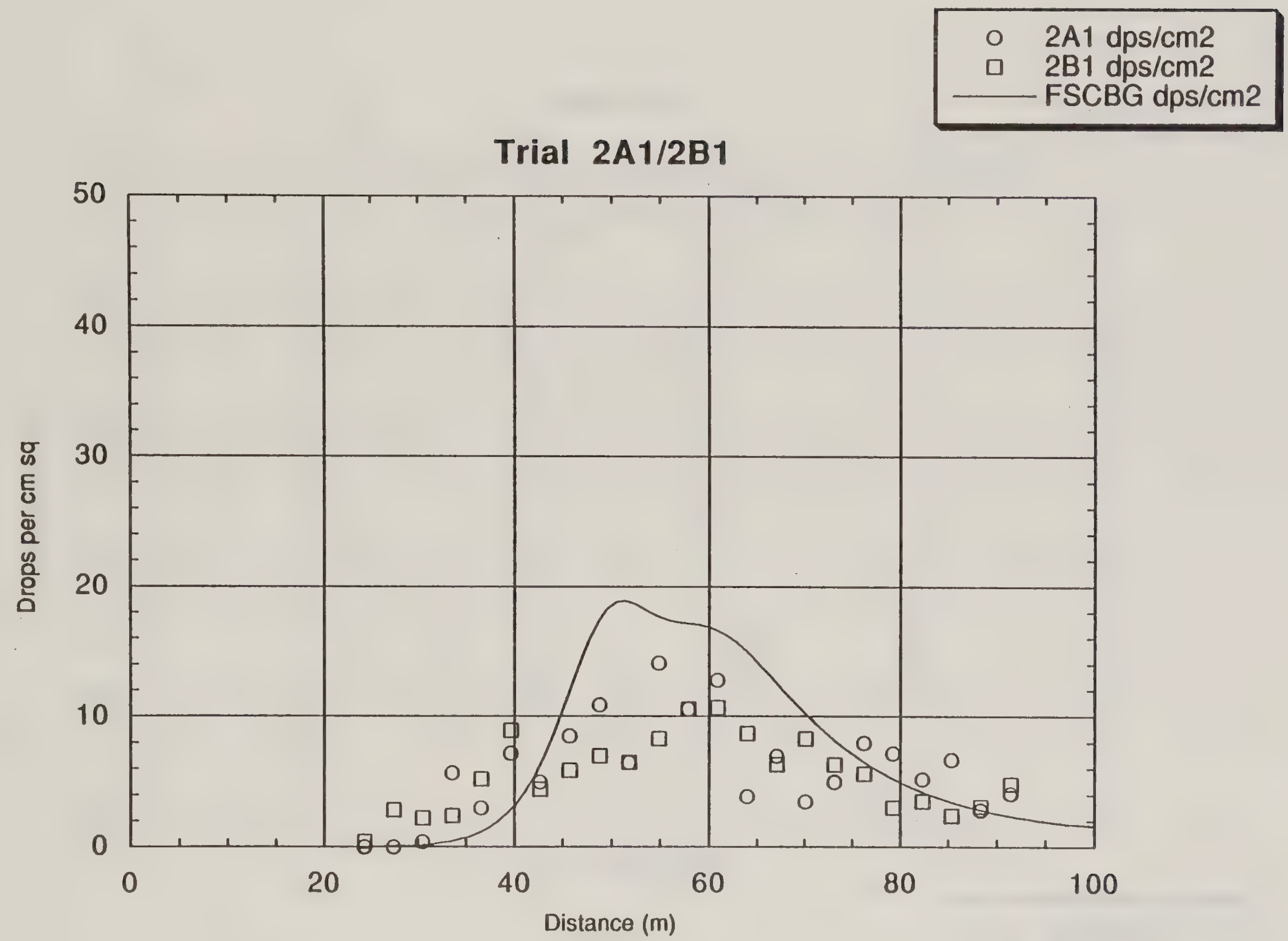
20
15
10
5
0
0
20
40
60
80
100
Distance (m)


1A2 oz/ac
1B2 oz/ac
FSCBG oz/ac
Trial 1A2/1B2
Volume (oz/ac)
100
80
60
40
20
0
20
30
40
50
60
70
80
90
100
Distance (m)

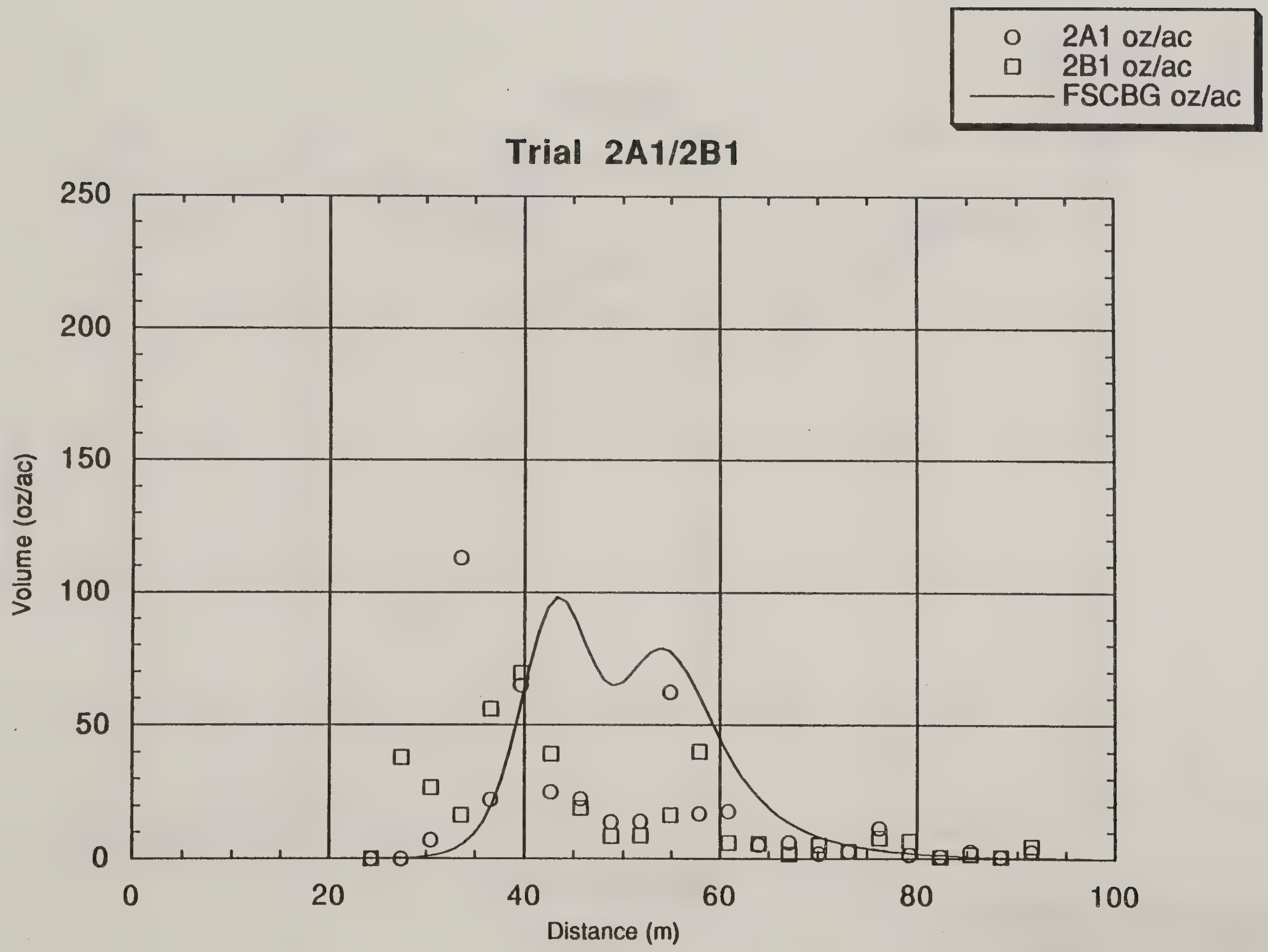

1A3 dps/cm2
1B3 dps/cm2
FSCBG dps/cm2
Trial 1A3/1B3
Drops per cm sq
25
20
15
10
5
0
0
20
40
60
80
100
Distance (m)

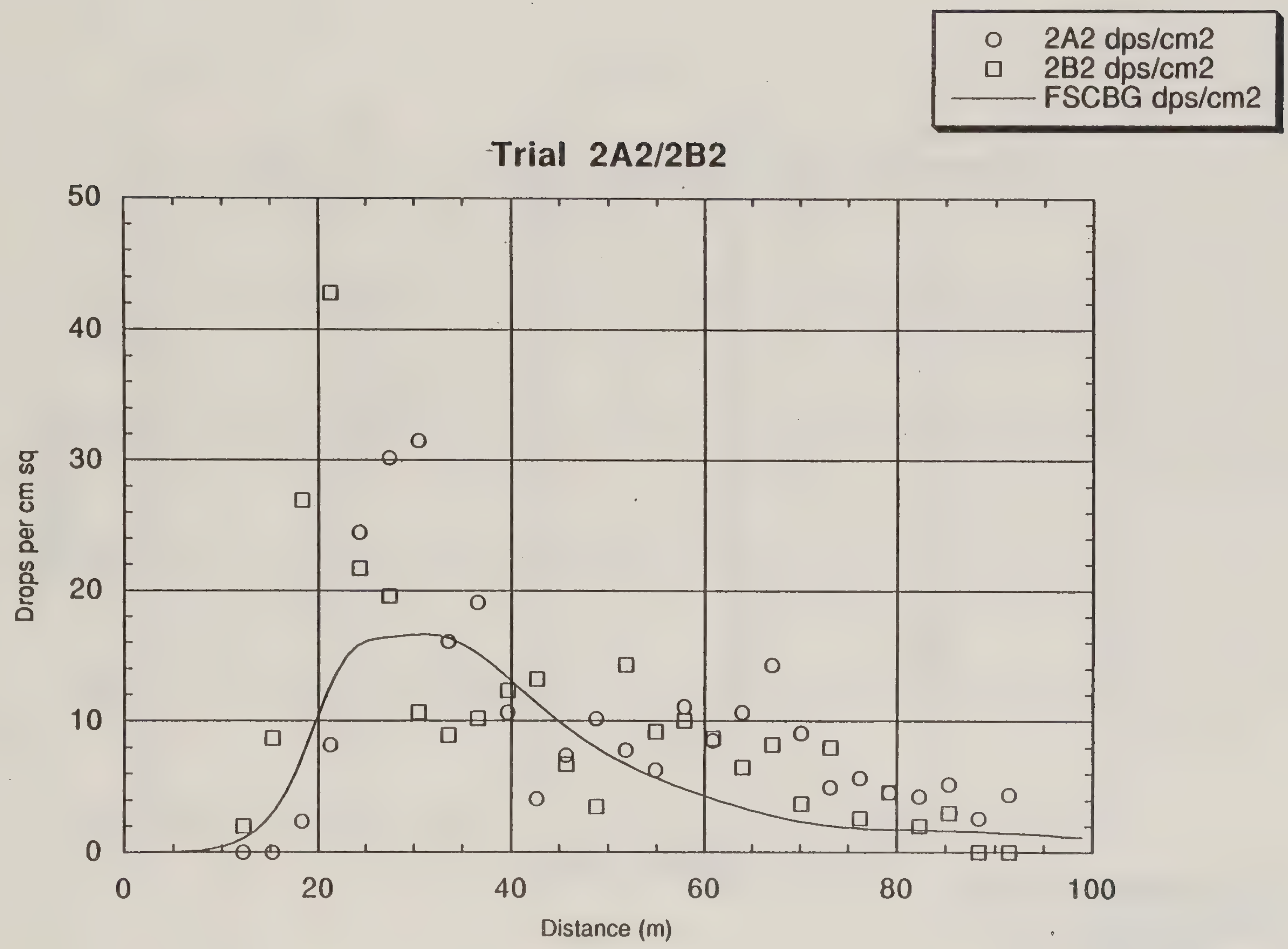


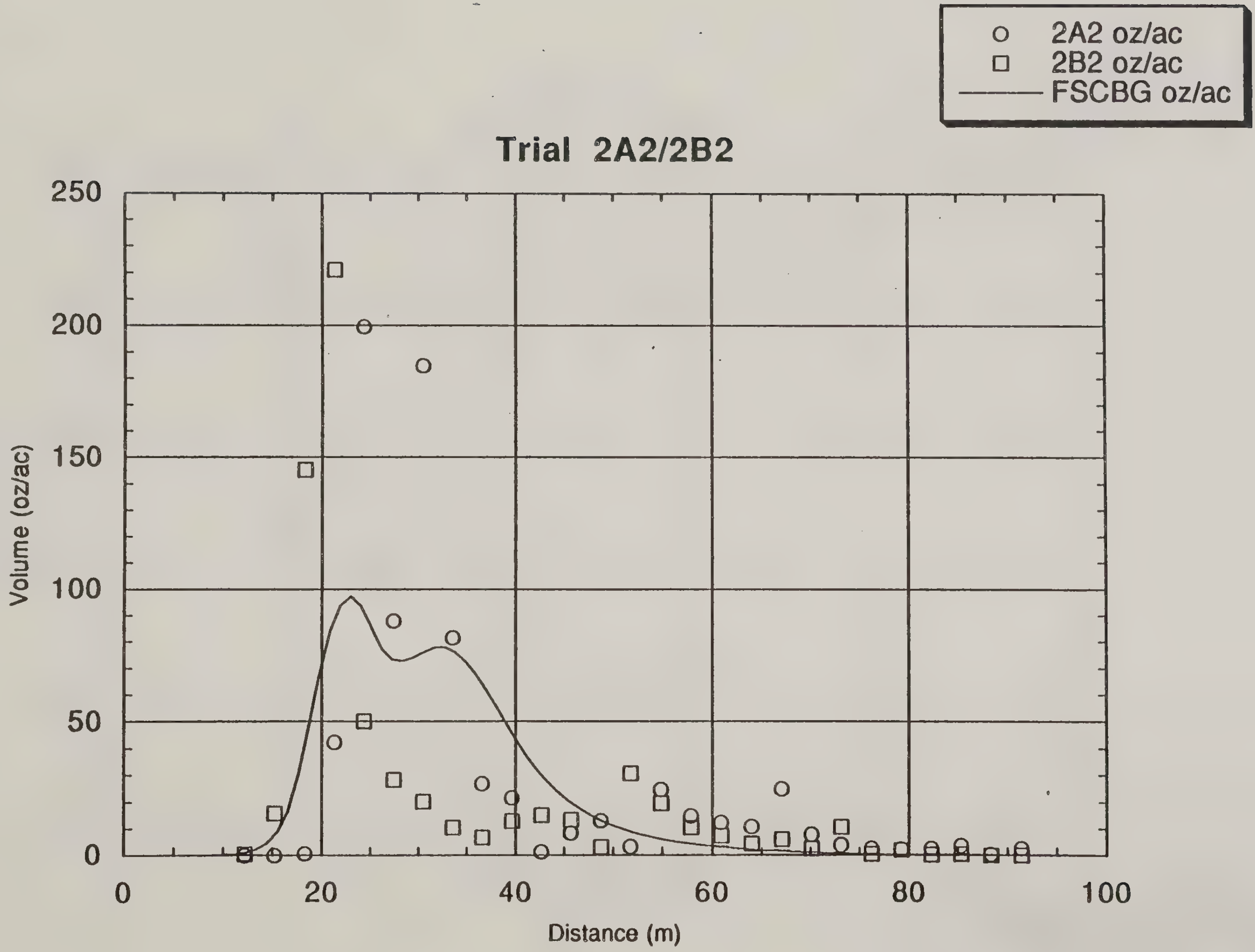
1A3 oz/ac
1B3 oz/ac
FSCBG oz/ac
Trial 1A3/1B3
100
80
60
40
20
0
Volume (oz/ac)
0
20
40
60
80
100
Distance (m)

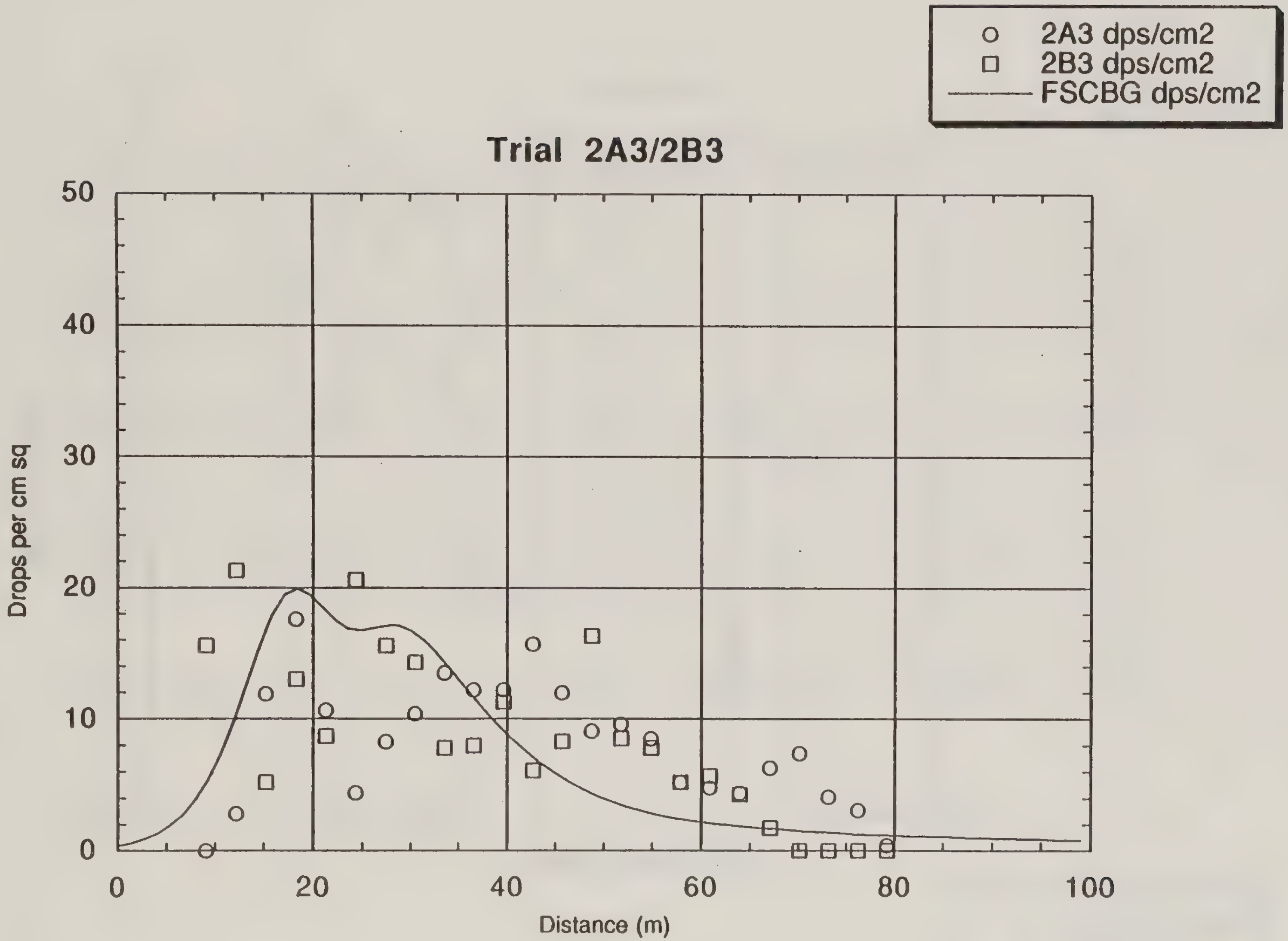


2A1 dps/cm2
2B1 dps/cm2
FSCBG dps/cm2
Trial 2A1/2B1
50
40
30
20
10
0
Drops per cm sq
0
20
40
60
80
100
Distance (m)


Trial 2A1/2B1
2A1 oz/ac
2B1 oz/ac
FSCBG oz/ac
250
200
150
100
50
0
Volume (oz/ac)
0
20
40
60
80
100
Distance (m)


2A2 dps/cm2
2B2 dps/cm2
FSCBG dps/cm2
Trial 2A2/2B2
Drops per cm sq
Distance (m)
0
10
20
30
40
50
0
20
40
60
80
100


2A2 oz/ac
2B2 oz/ac
FSCBG oz/ac
Trial 2A2/2B2
Volume (oz/ac)
250
200
150
100
50
0
0
20
40
60
80
100
Distance (m)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2B3 dps/cm2
FSCBG dps/cm2
Trial 2A3/2B3
Drops per cm sq
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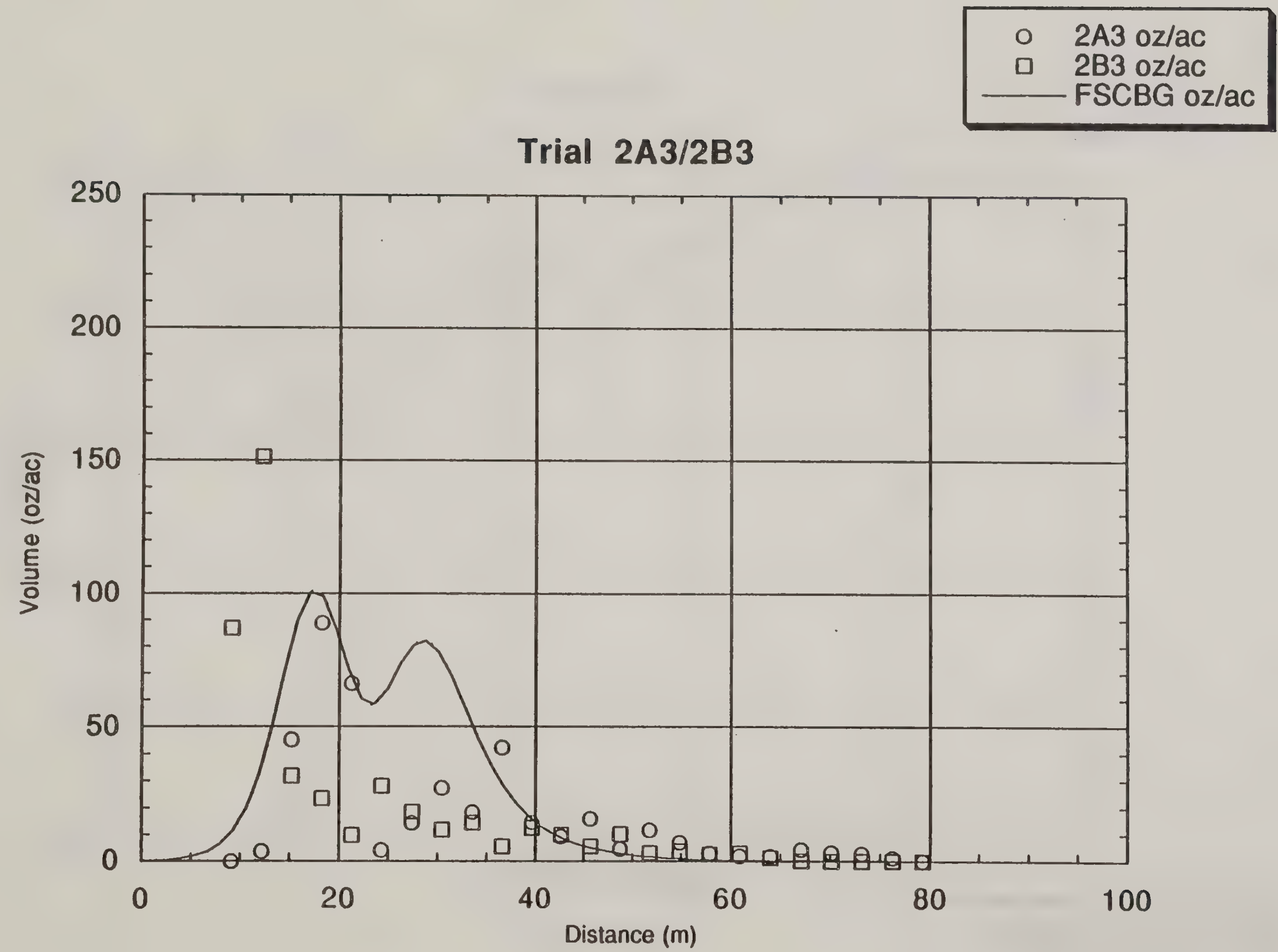
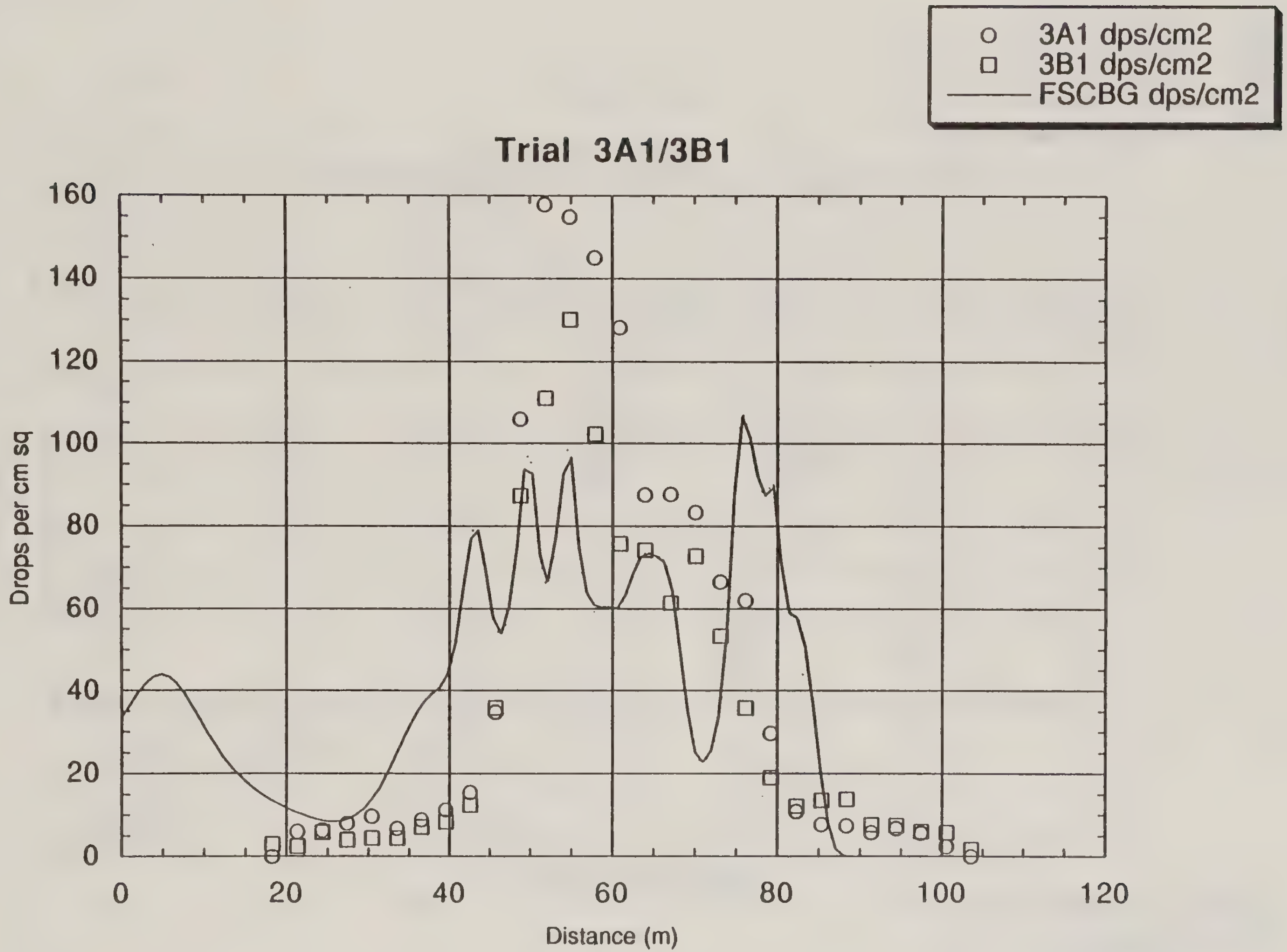
10
20
30
40
50
0
20
40
60
80
100
Distance (m)



2A3 oz/ac
2B3 oz/ac
FSCBG oz/ac
Trial 2A3/2B3
250
200
150
100
50
0
Volume (oz/ac)
0
20
40
60
80
100
Distance (m)


3A1 dps/cm2
3B1 dps/cm2
FSCBG dps/cm2
Trial 3A1/3B1
Drops per cm sq
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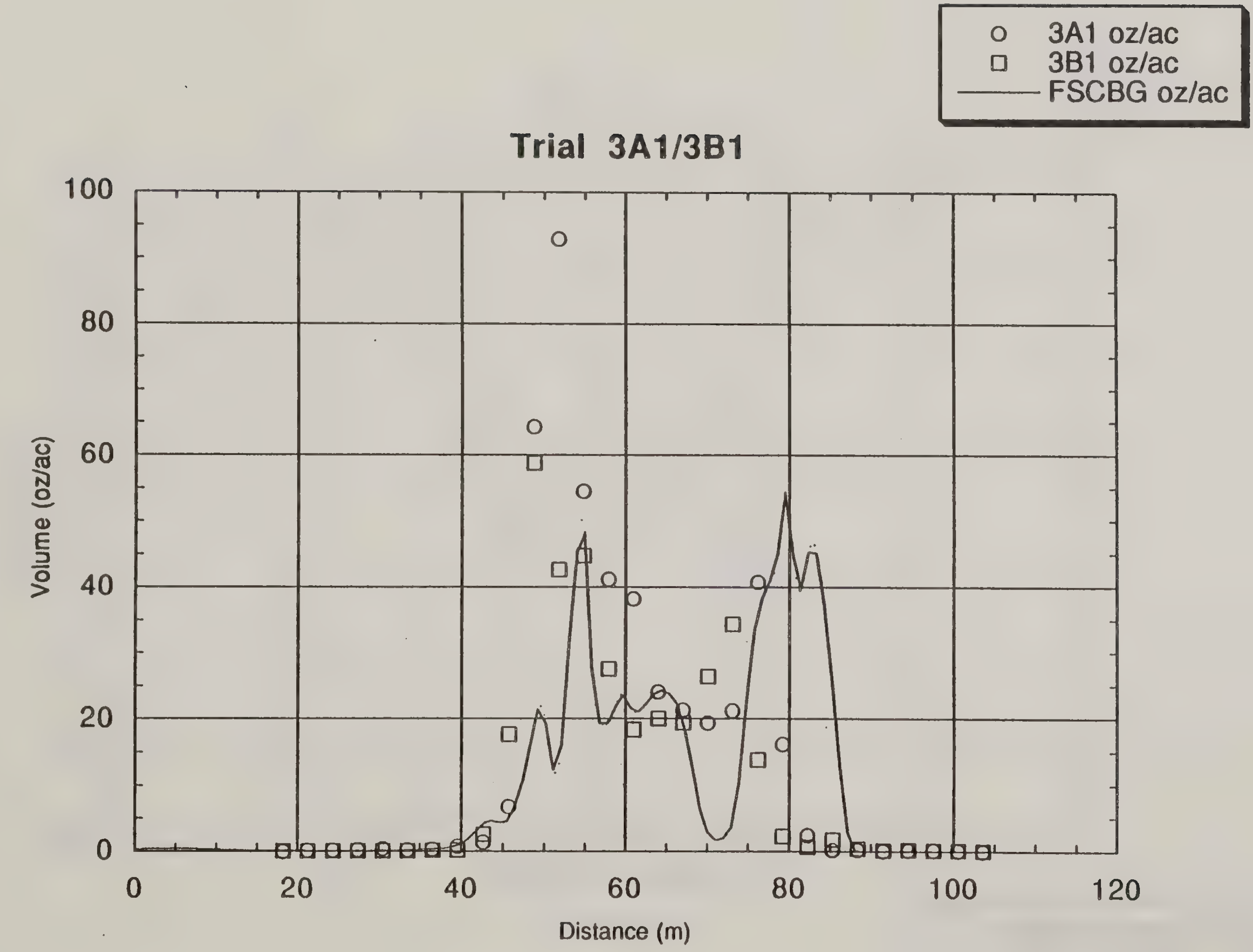
40
60
80
100
120
140
160
0
20
40
60
80
100
120
Distance (m)


3A1 oz/ac
3B1 oz/ac
FSCBG oz/ac
Trial 3A1/3B1
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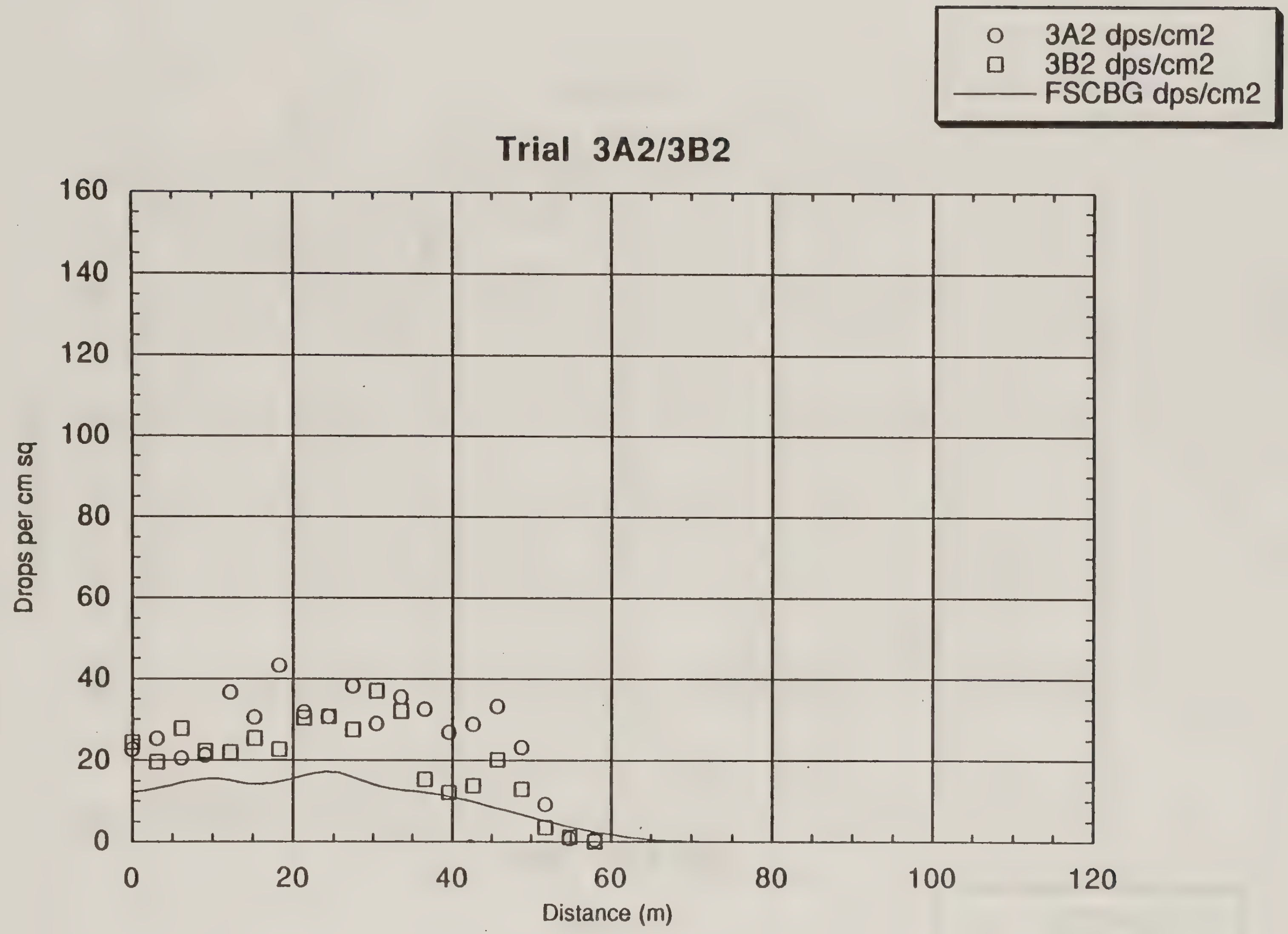
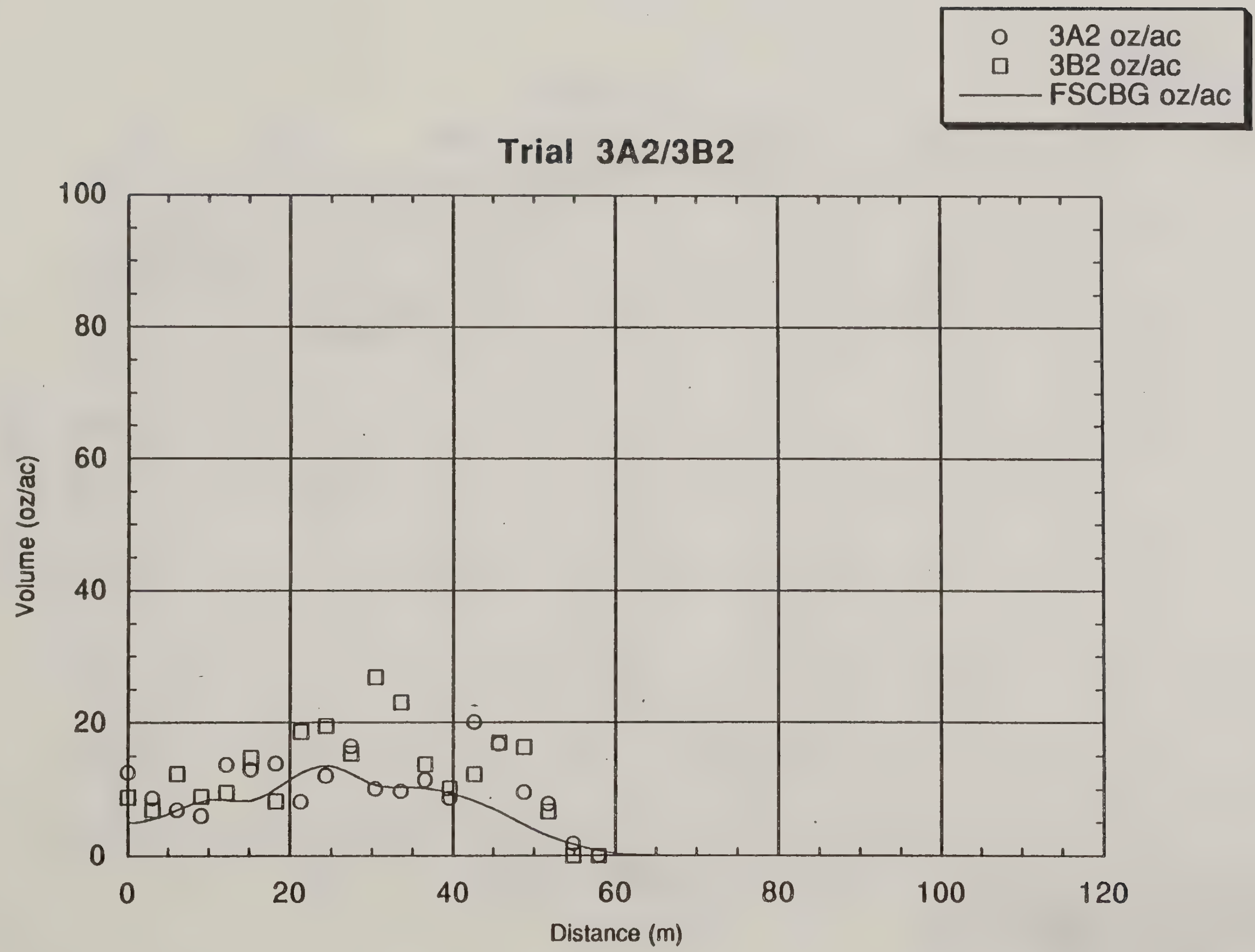
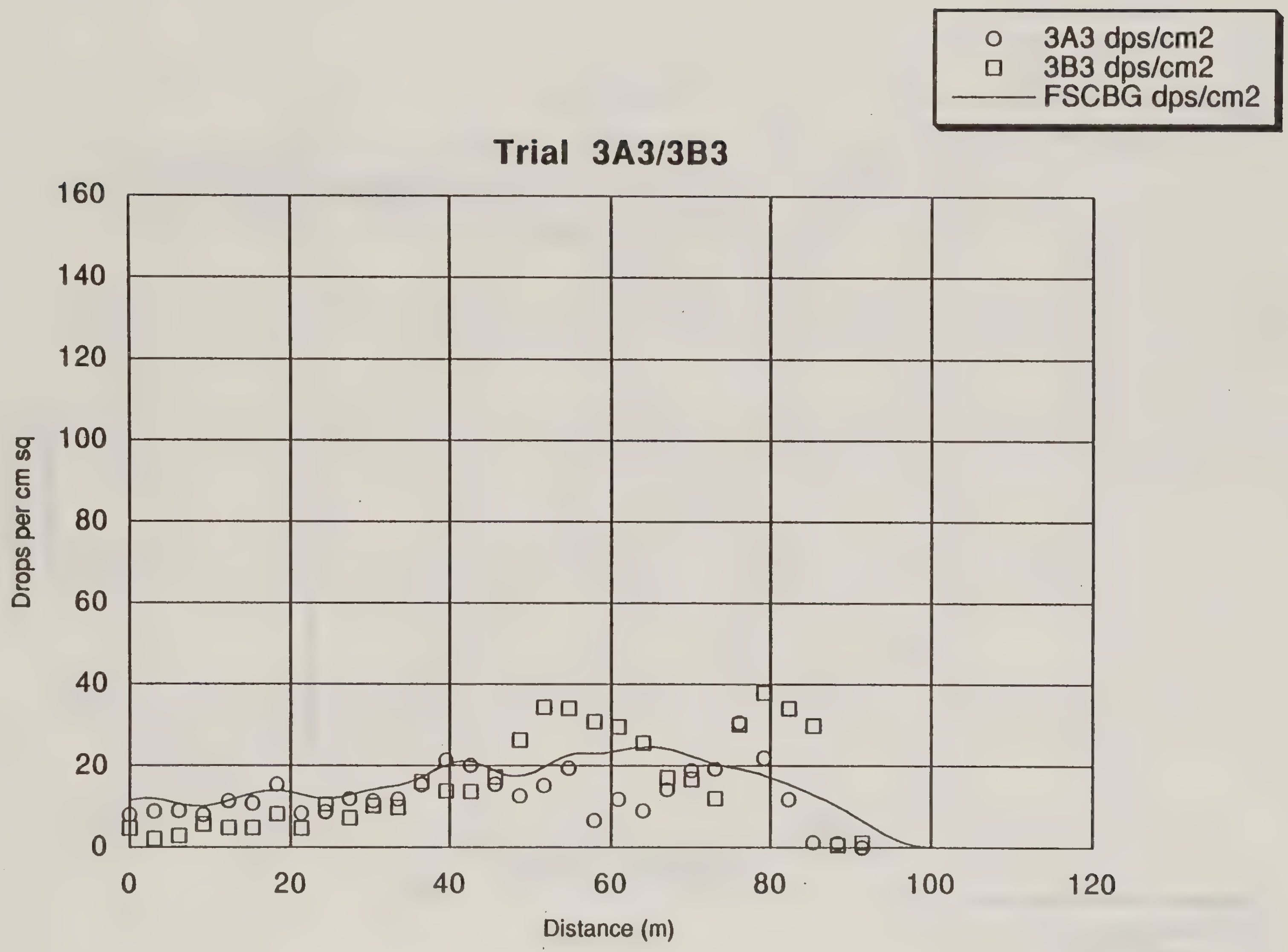
80
60
40
20
0
Volume (oz/ac)
0
20
40
60
80
100
120
Distance (m)

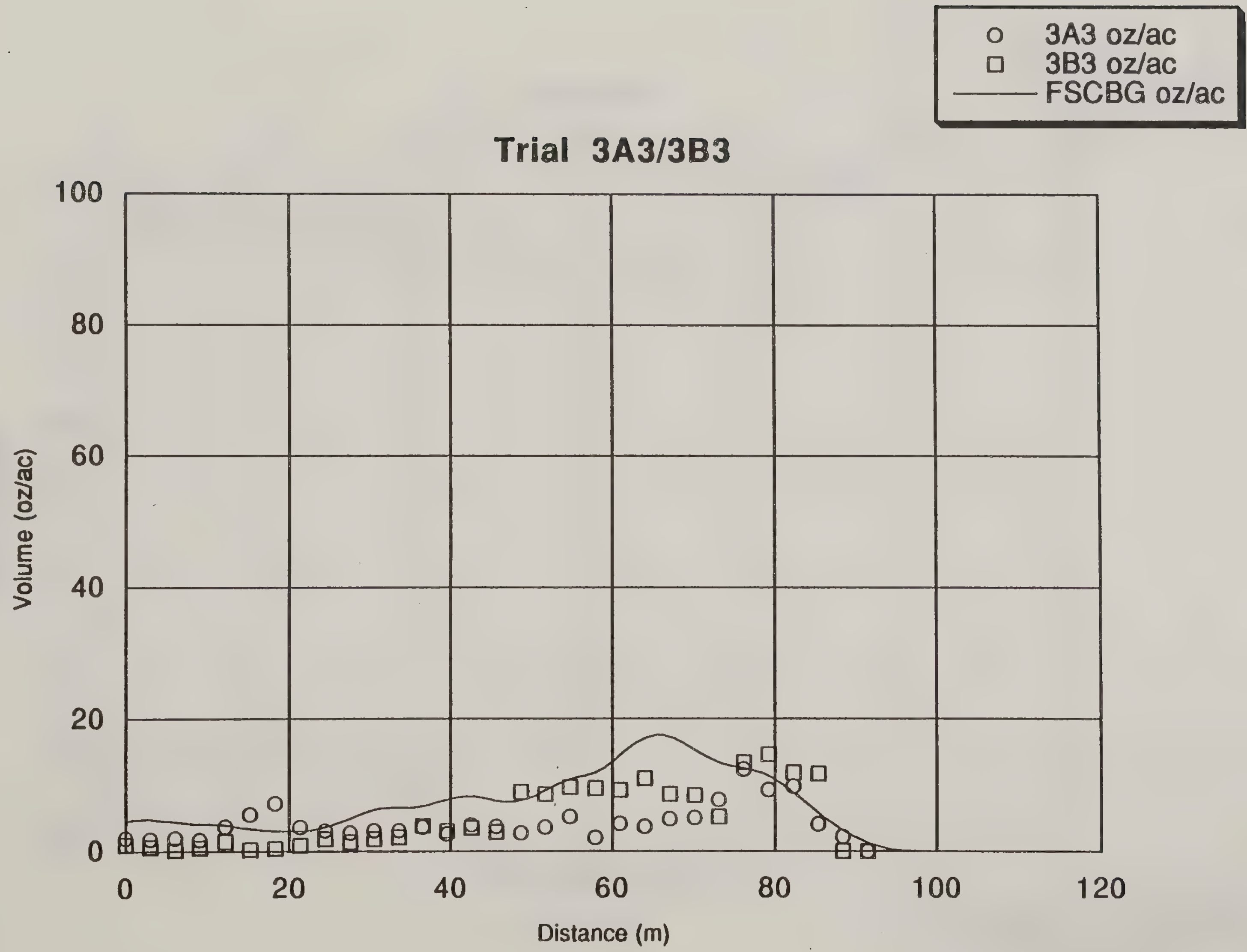


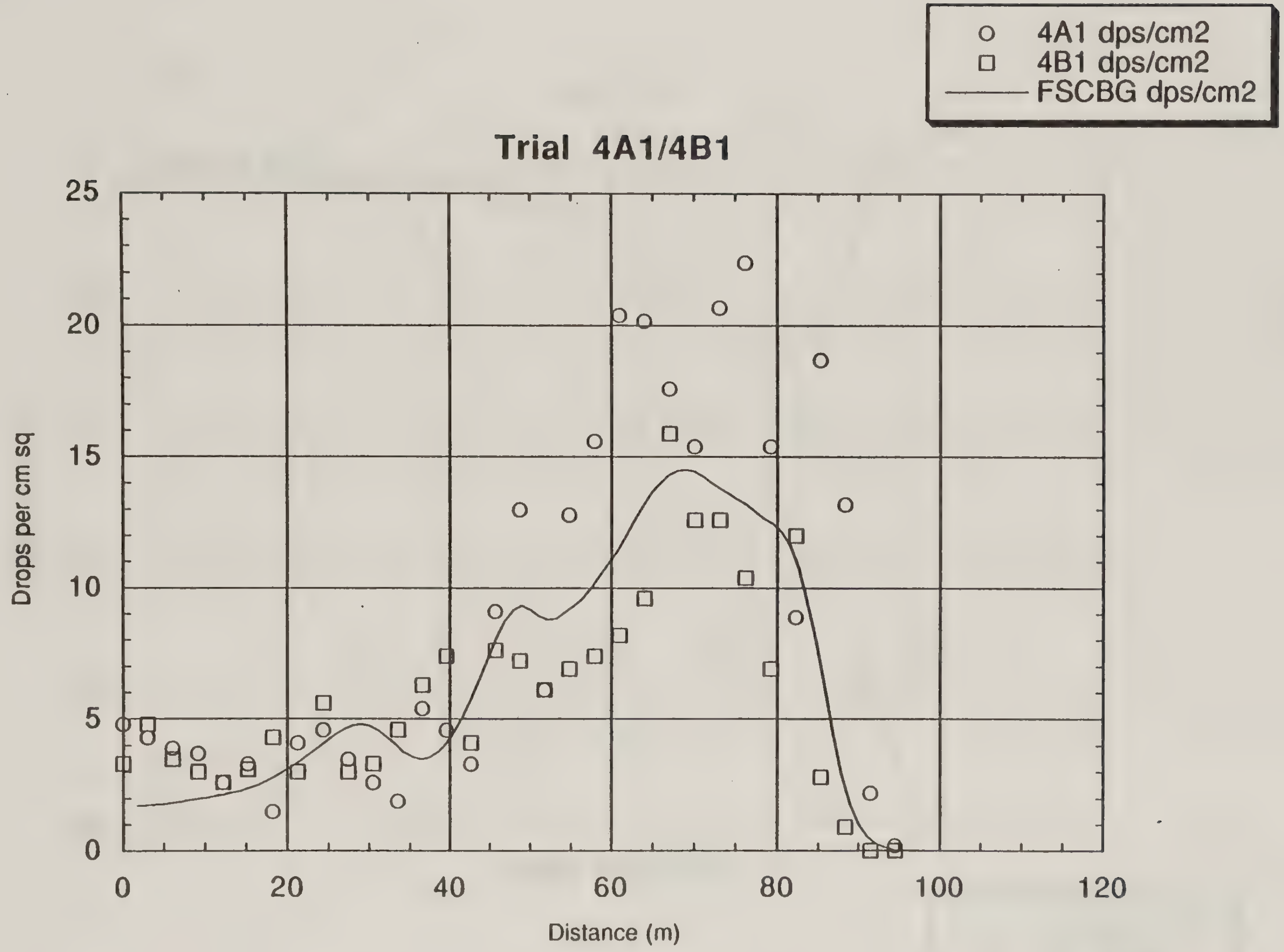
Trial 3A2/3B2
3A2 dps/cm2
3B2 dps/cm2
FSCBG dps/cm2
Drops per cm sq
160
140
120
100
80
60
40
20
0
0
20
40
60
80
100
120
Distance (m)

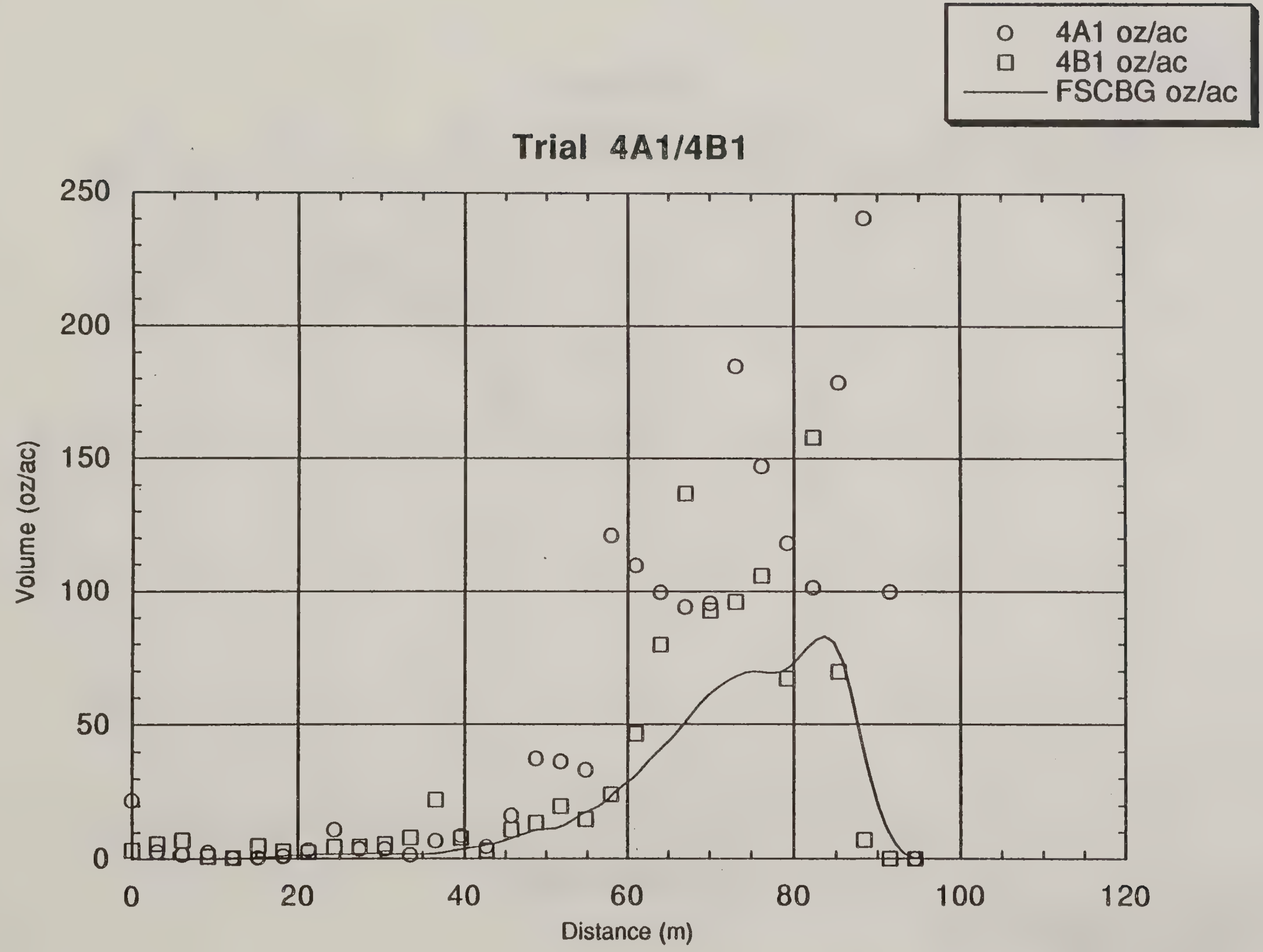

Trial 3A2/3B2
3A2 oz/ac
3B2 oz/ac
FSCBG oz/ac
Volume (oz/ac)
0
20
40
60
80
100
0
20
40
60
80
100
120
Distance (m)

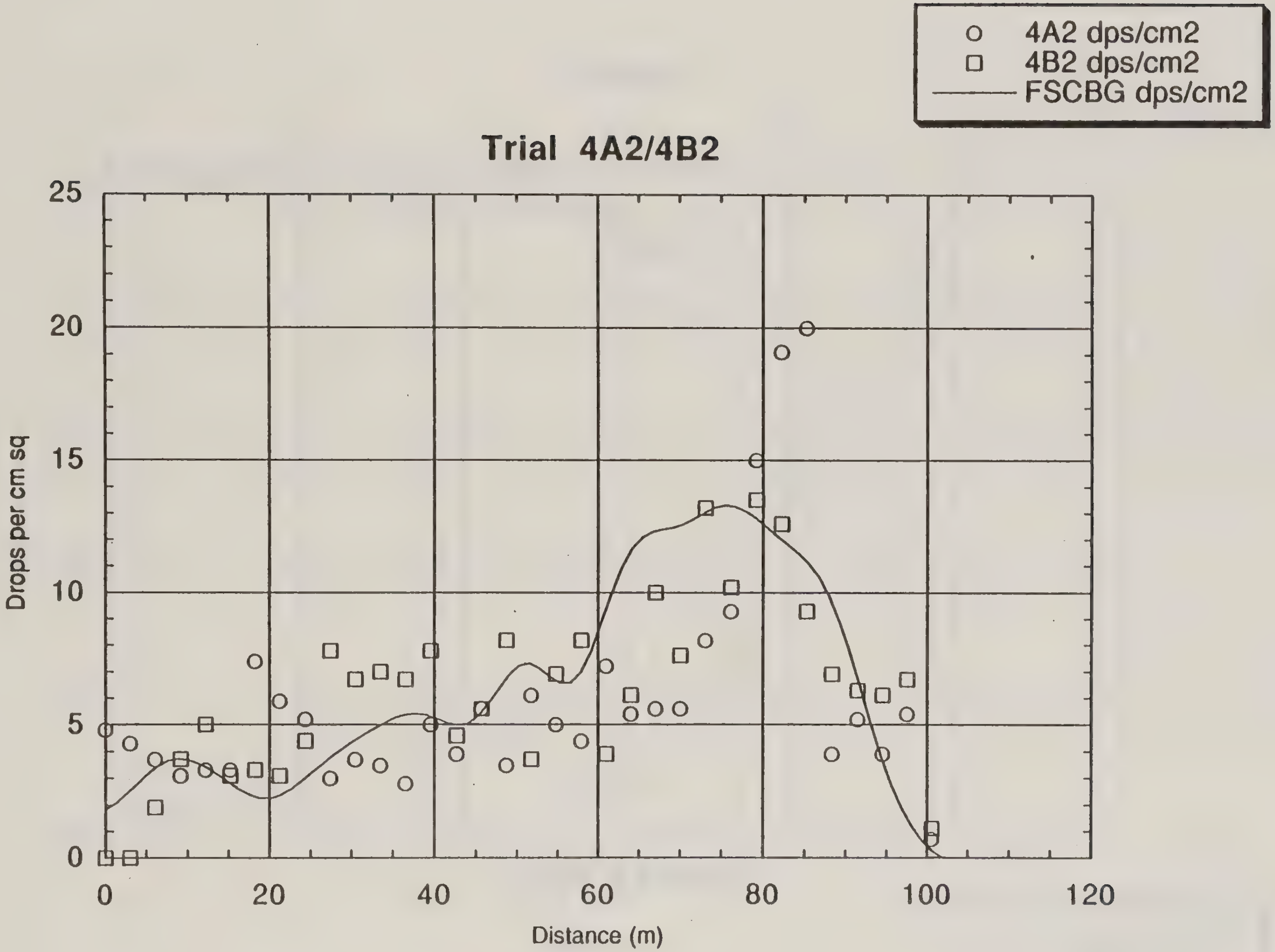


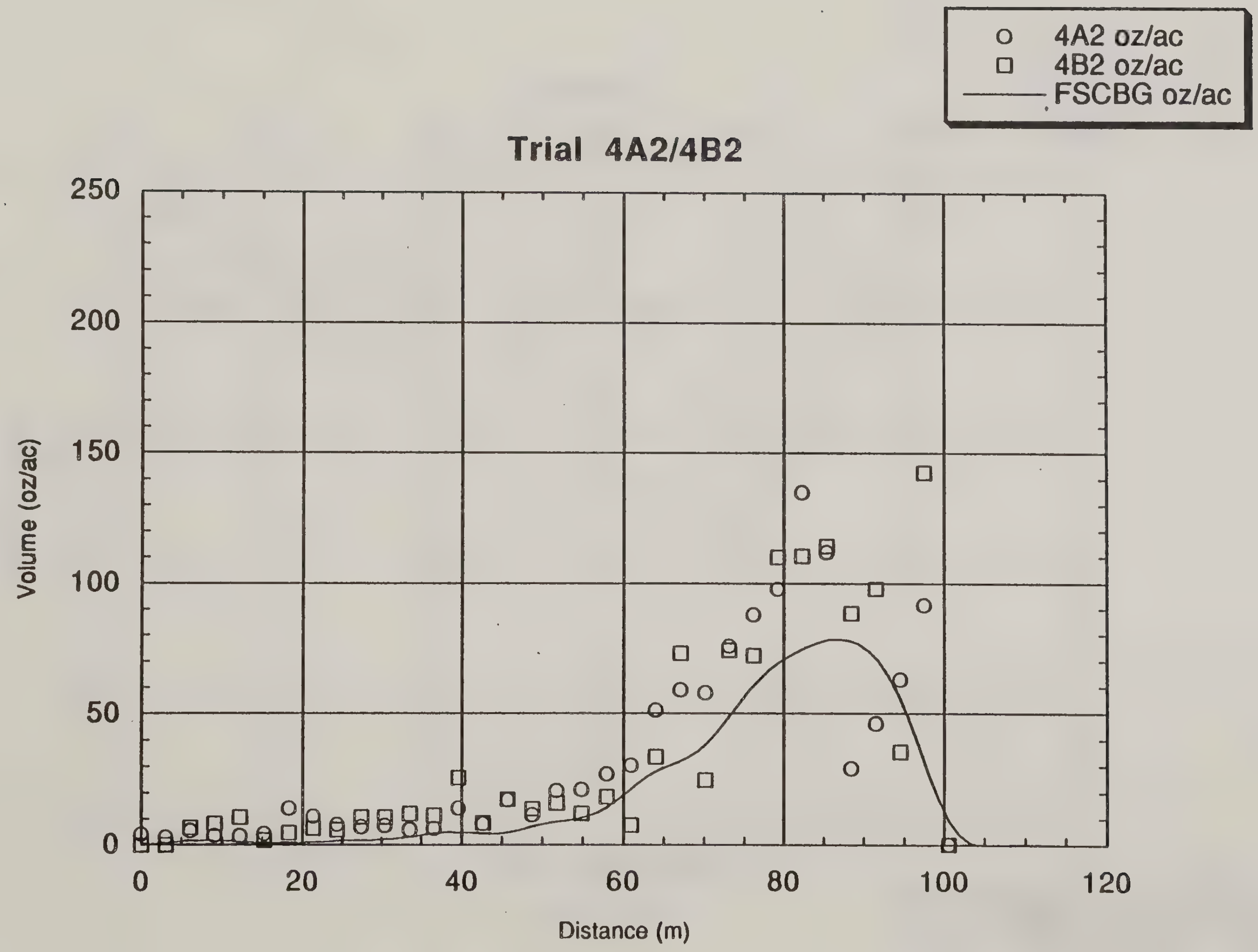
3A3 dps/cm2
3B3 dps/cm2
FSCBG dps/cm2
Trial 3A3/3B3
Drops per cm sq
Distance (m)


3A3 oz/ac
3B3 oz/ac
FSCBG oz/ac
Trial 3A3/3B3
100
80
60
40
20
0
Volume (oz/ac)
0
20
40
60
80
100
120
Distance (m)

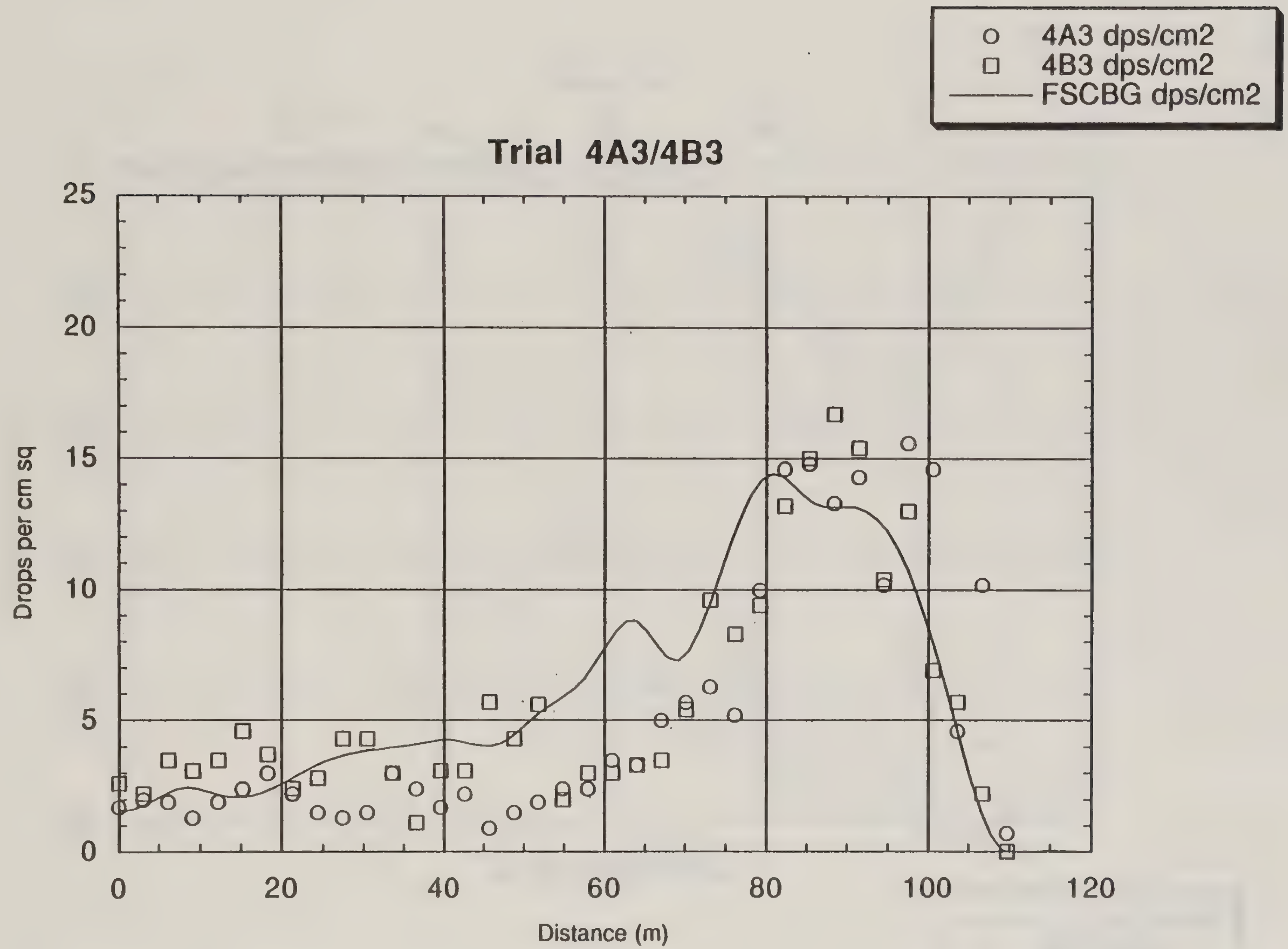

Trial 4A1/4B1
4A1 dps/cm2
4B1 dps/cm2
FSCBG dps/cm2
Drops per cm sq
Distance (m)
0
5
10
15
20
25
0
20
40
60
80
100
120


Trial 4A1/4B1
4A1 oz/ac
4B1 oz/ac
FSCBG oz/ac
Volume (oz/ac)
Distance (m)
0
50
100
150
200
250
0
20
40
60
80
100
120

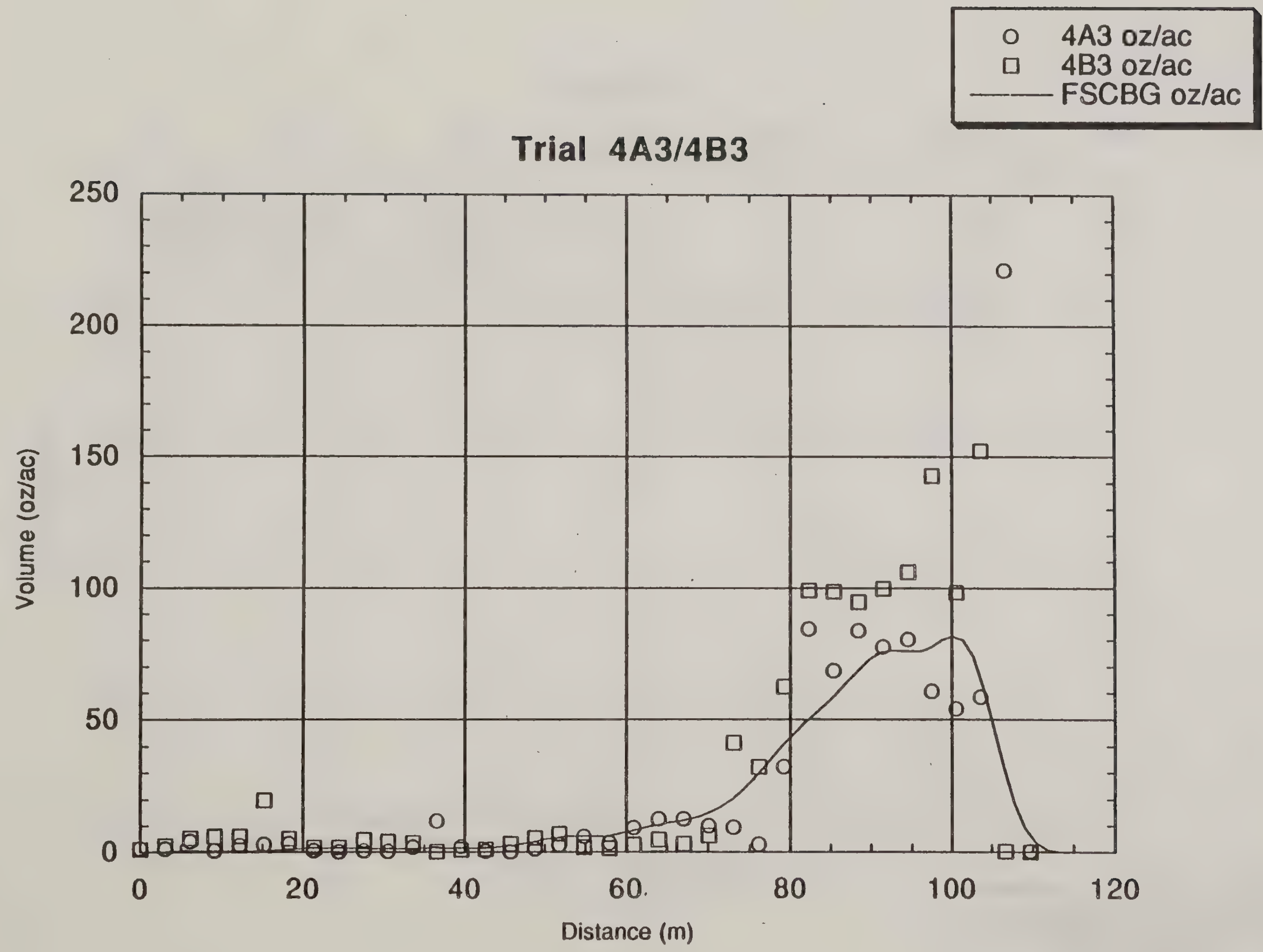

4A2 dps/cm2
4B2 dps/cm2
FSCBG dps/cm2
Trial 4A2/4B2
Drops per cm sq
0
5
10
15
20
25
0
20
40
60
80
100
120
Distance (m)



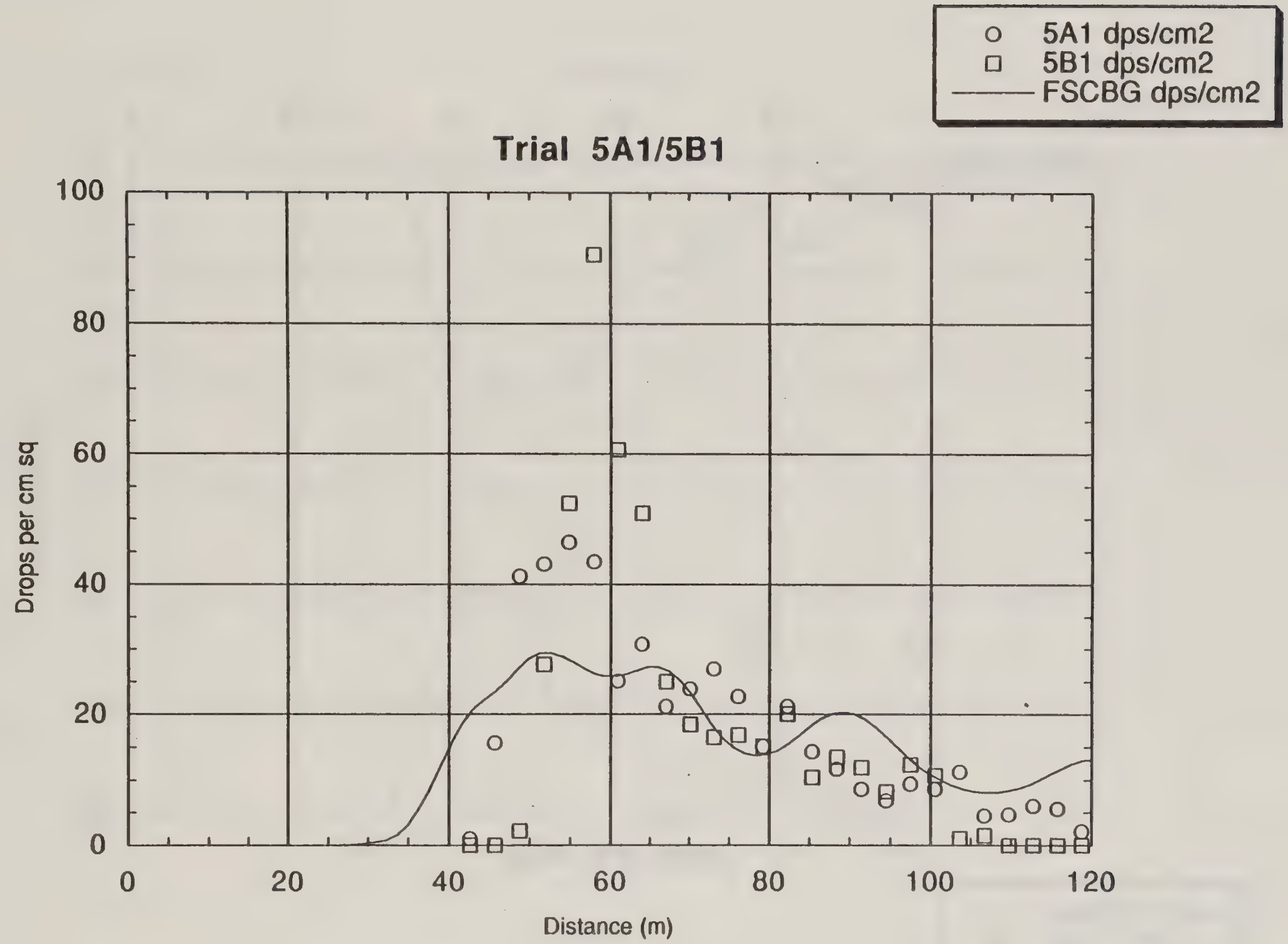
4A2 oz/ac
4B2 oz/ac
FSCBG oz/ac
Trial 4A2/4B2
250
200
150
100
50
0
Volume (oz/ac)
0
20
40
60
80
100
120
Distance (m)



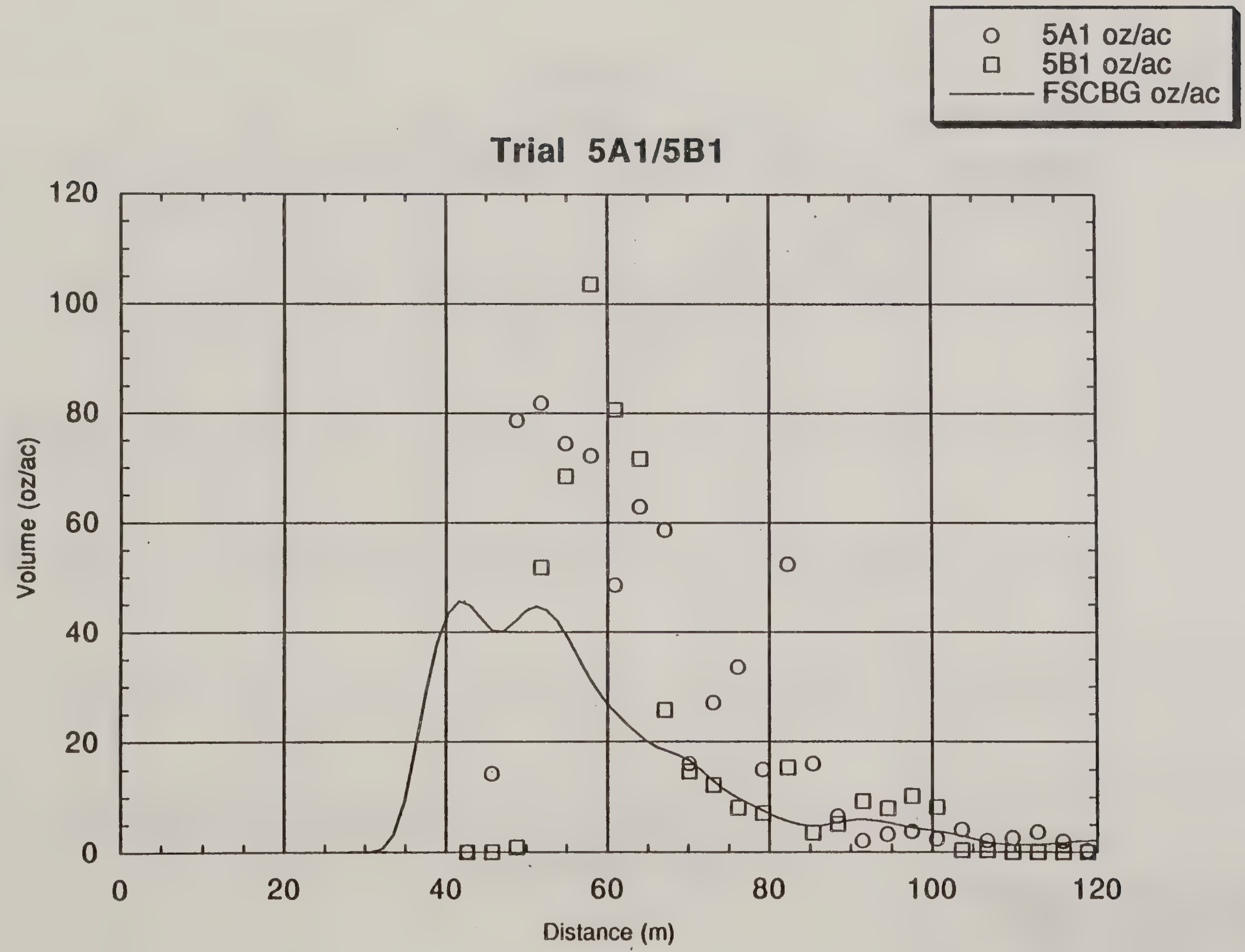
Trial 4A3/4B3
4A3 dps/cm2
4B3 dps/cm2
FSCBG dps/cm2
Drops per cm sq
Distance (m)
0
5
10
15
20
25
0
20
40
60
80
100
120



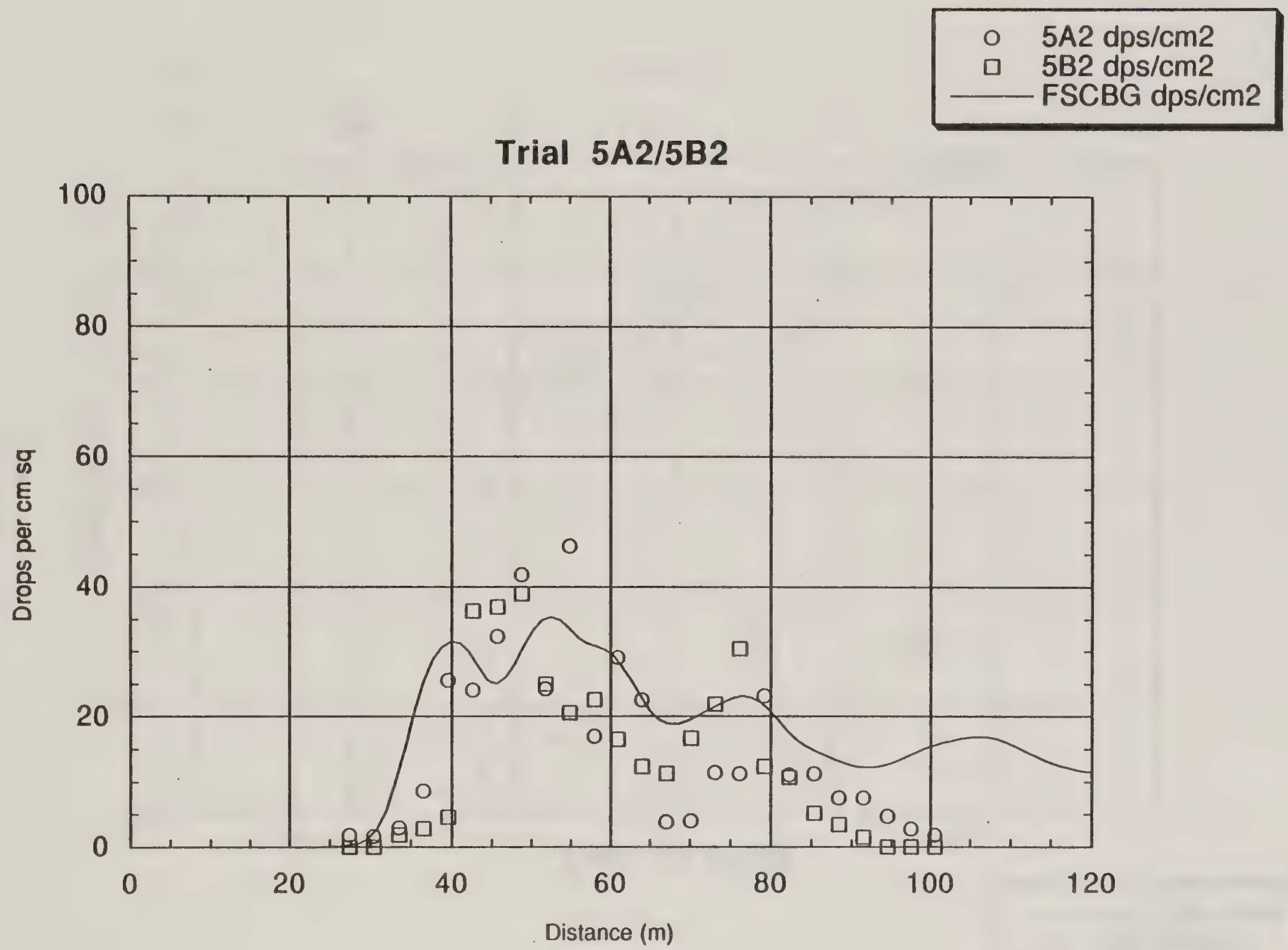
Trial 4A3/4B3
4A3 oz/ac
4B3 oz/ac
FSCBG oz/ac
Volume (oz/ac)
Distance (m)
0
50
100
150
200
250
0
20
40
60
80
100
120

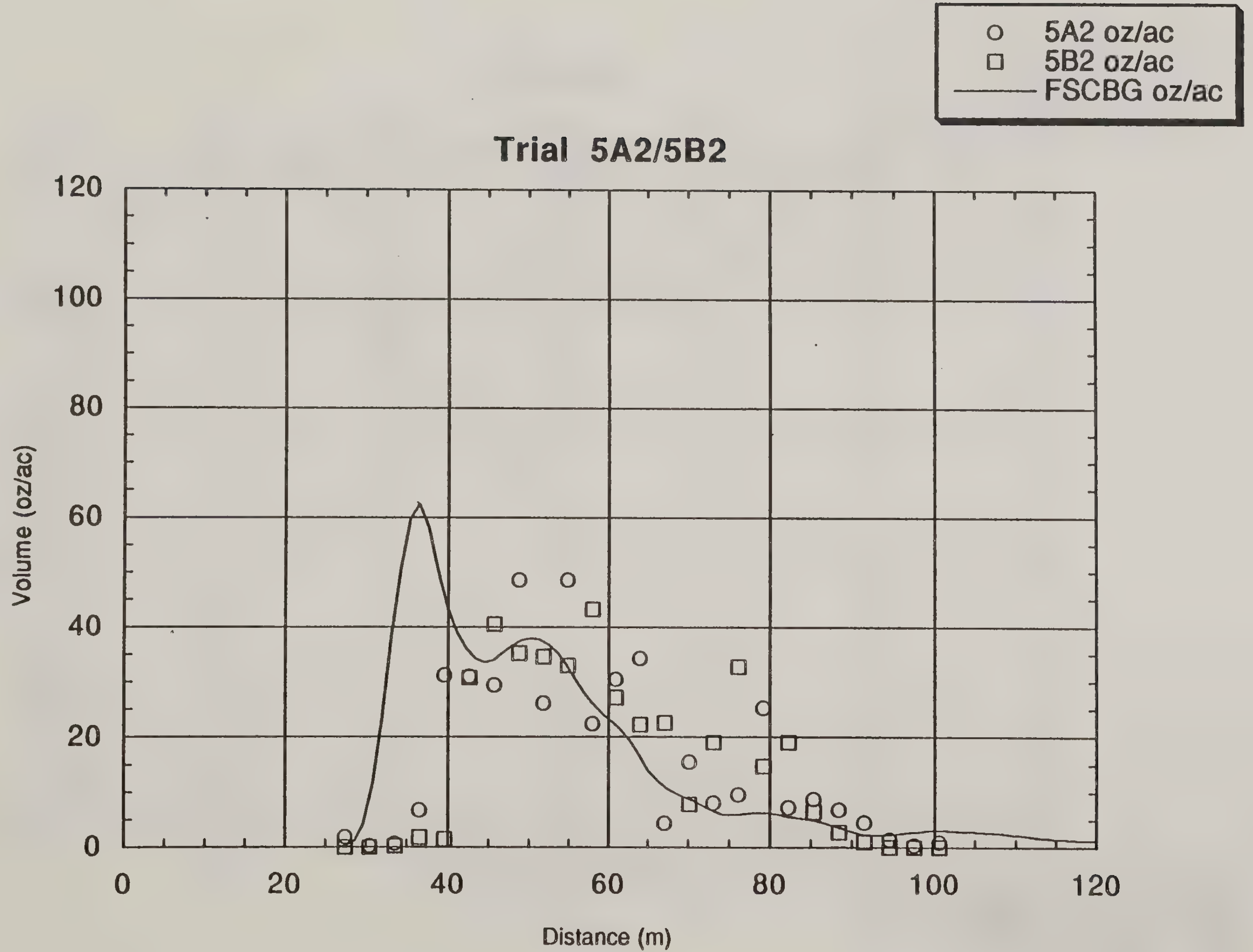


Trial 5A1/5B1
5A1 dps/cm2
5B1 dps/cm2
FSCBG dps/cm2
Drops per cm sq
0
20
40
60
80
100
0
20
40
60
80
100
120
Distance (m)

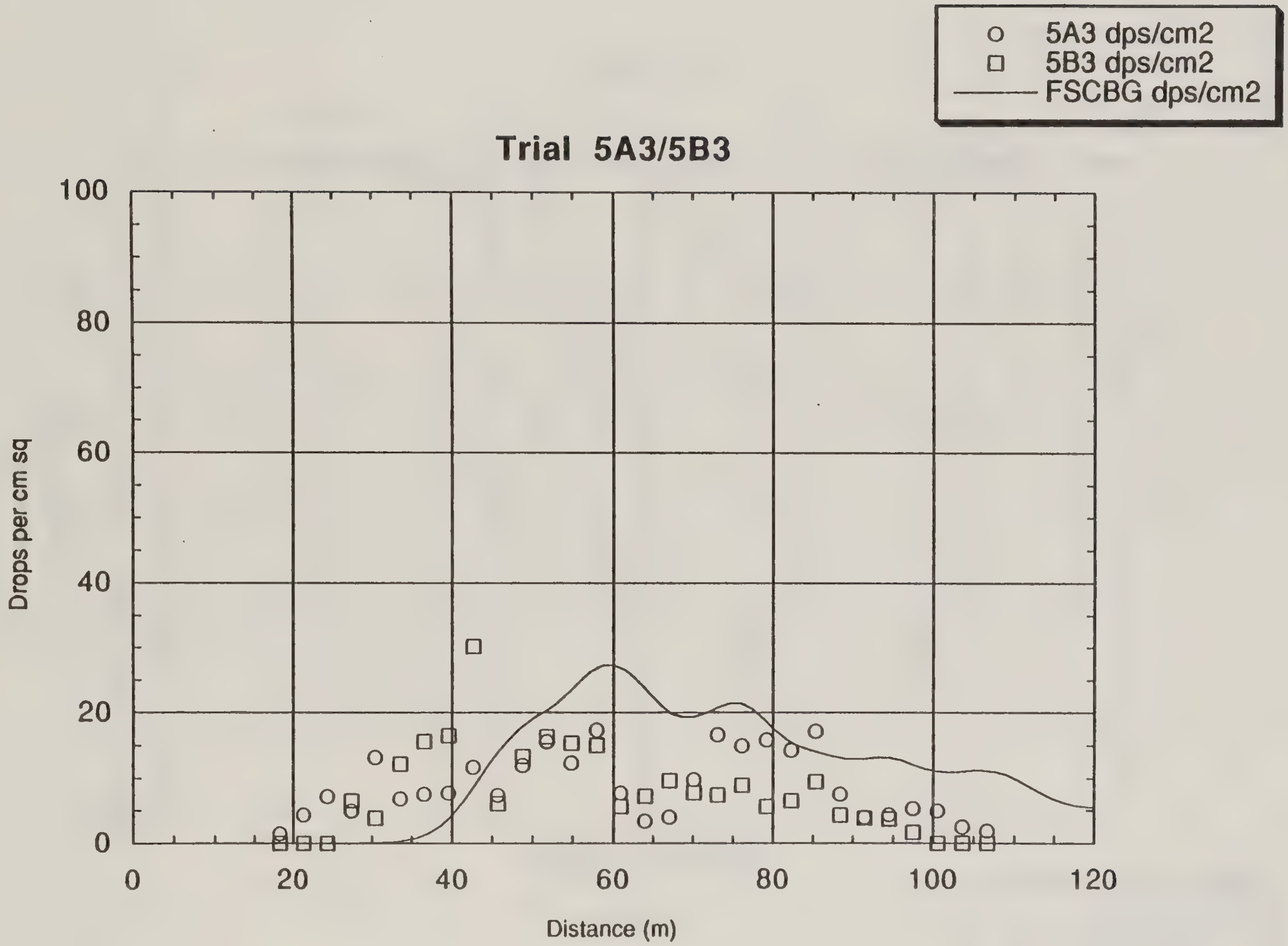


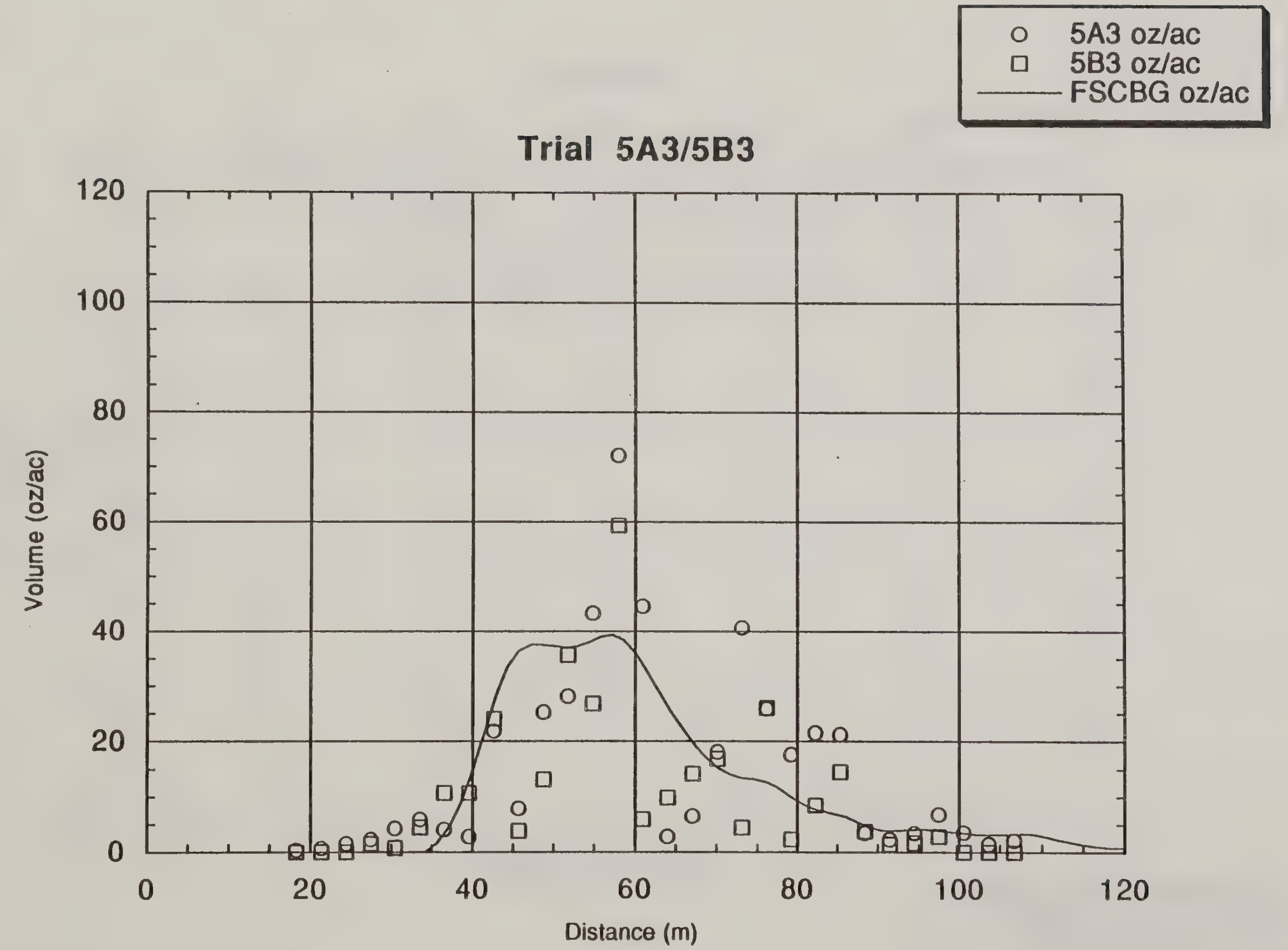
5A1 oz/ac
5B1 oz/ac
FSCBG oz/ac
Trial 5A1/5B1
120
100
80
60
40
20
0
Volume (oz/ac)
0
20
40
60
80
100
120
Distance (m)


Trial 5A2/5B2
5A2 dps/cm2
5B2 dps/cm2
FSCBG dps/cm2
Drops per cm sq
100
80
60
40
20
0
0
20
40
60
80
100
120
Distance (m)

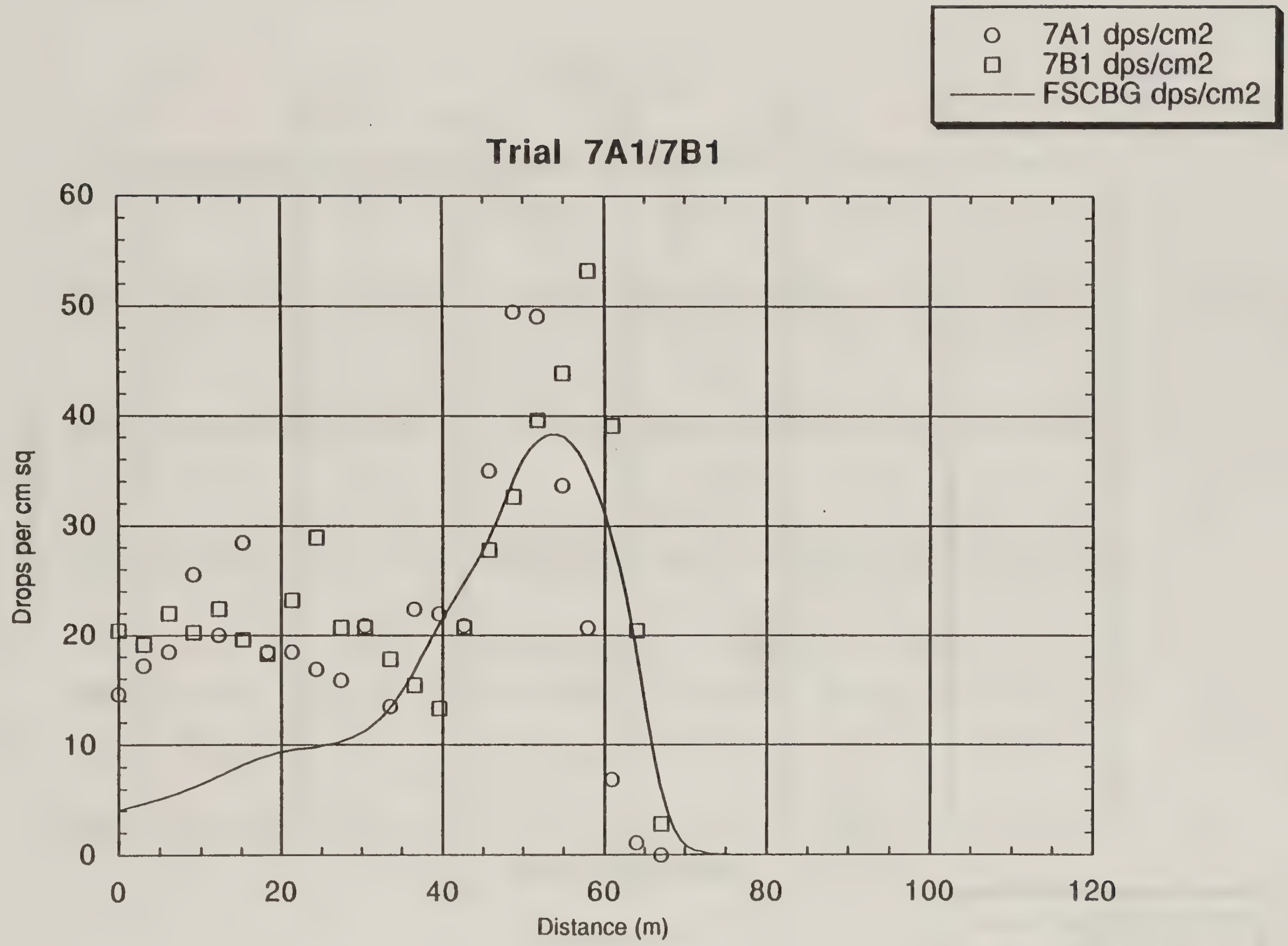

5A2 oz/ac
5B2 oz/ac
FSCBG oz/ac
Trial 5A2/5B2
Volume (oz/ac)
0
20
40
60
80
100
120
Distance (m)

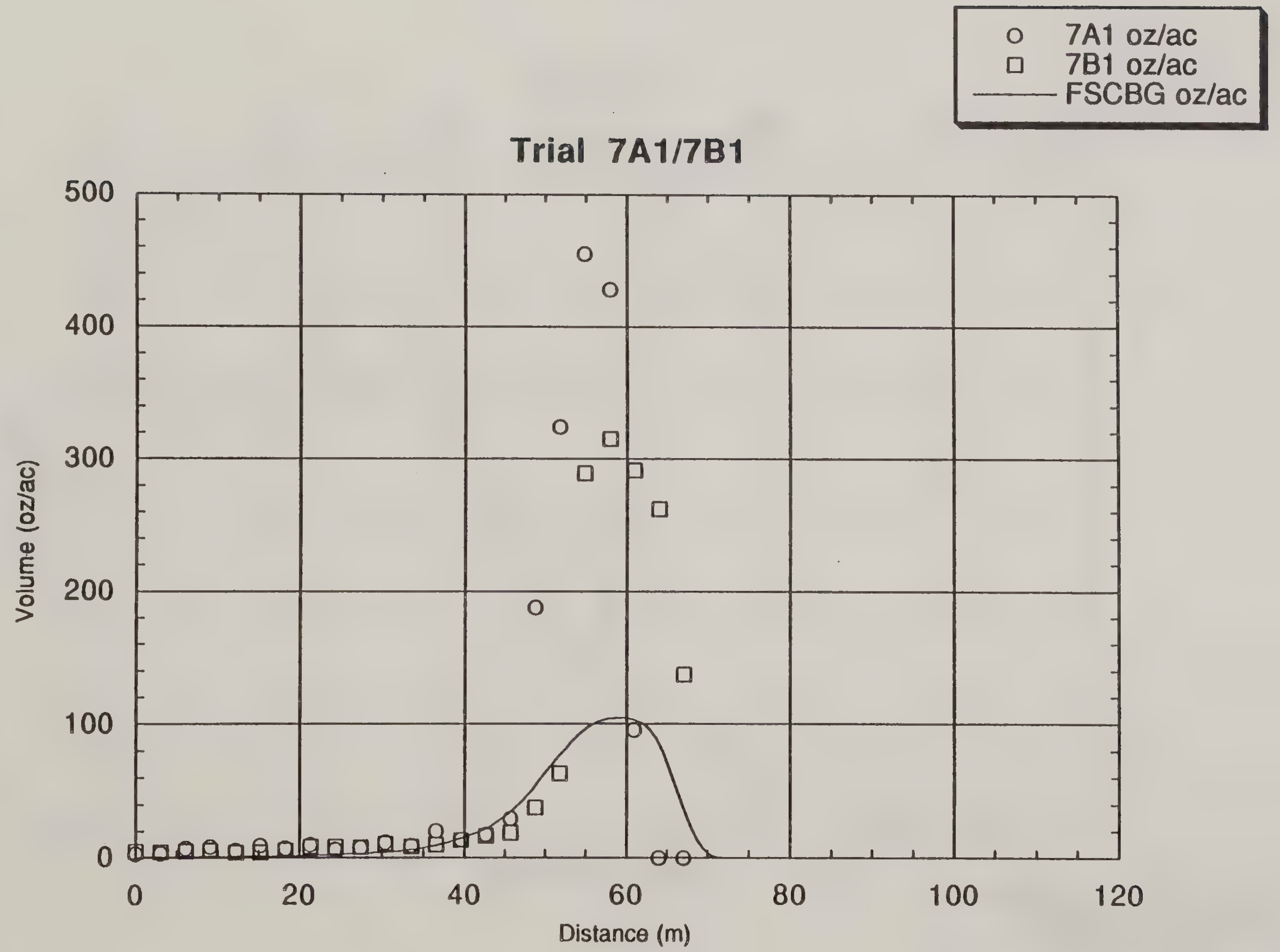
Trial 5A3/5B3



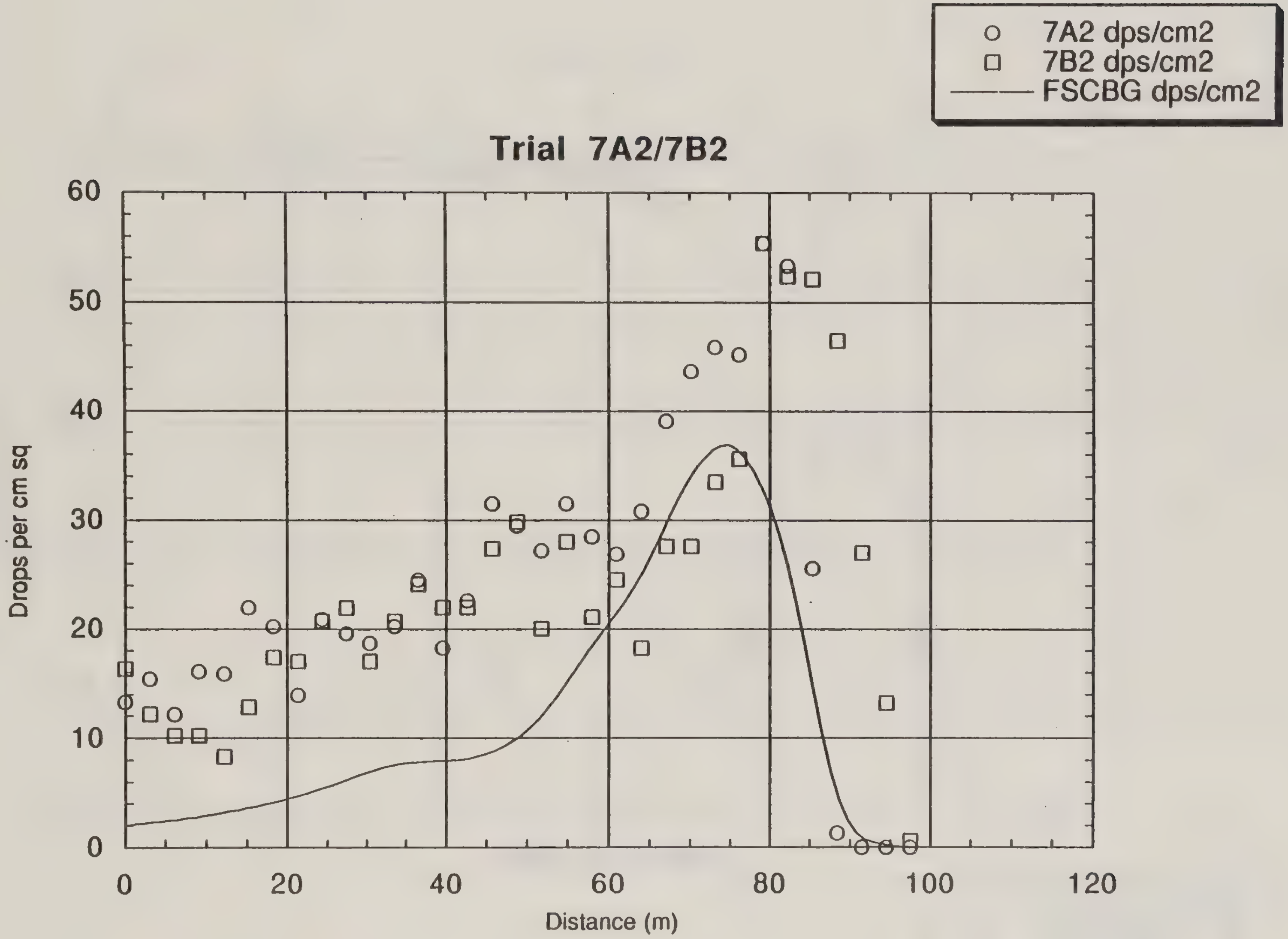


5A3 oz/ac
5B3 oz/ac
FSCBG oz/ac
Trial 5A3/5B3
Volume (oz/ac)
0
20
40
60
80
100
120
Distance (m)

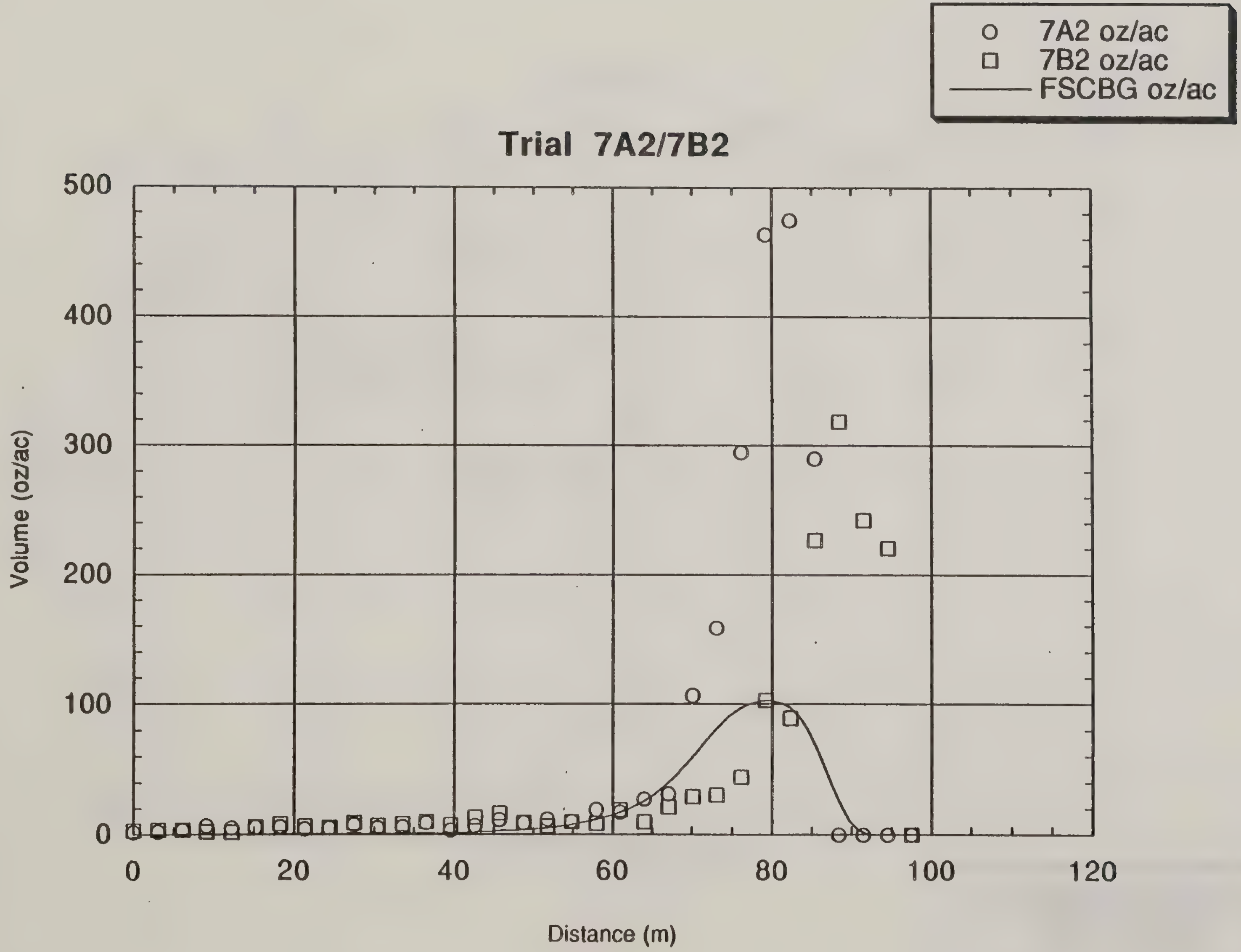

7A1 dps/cm2
7B1 dps/cm2
FSCBG dps/cm2
Trial 7A1/7B1
Drops per cm sq
0
10
20
30
40
50
60
0
20
40
60
80
100
120
Distance (m)



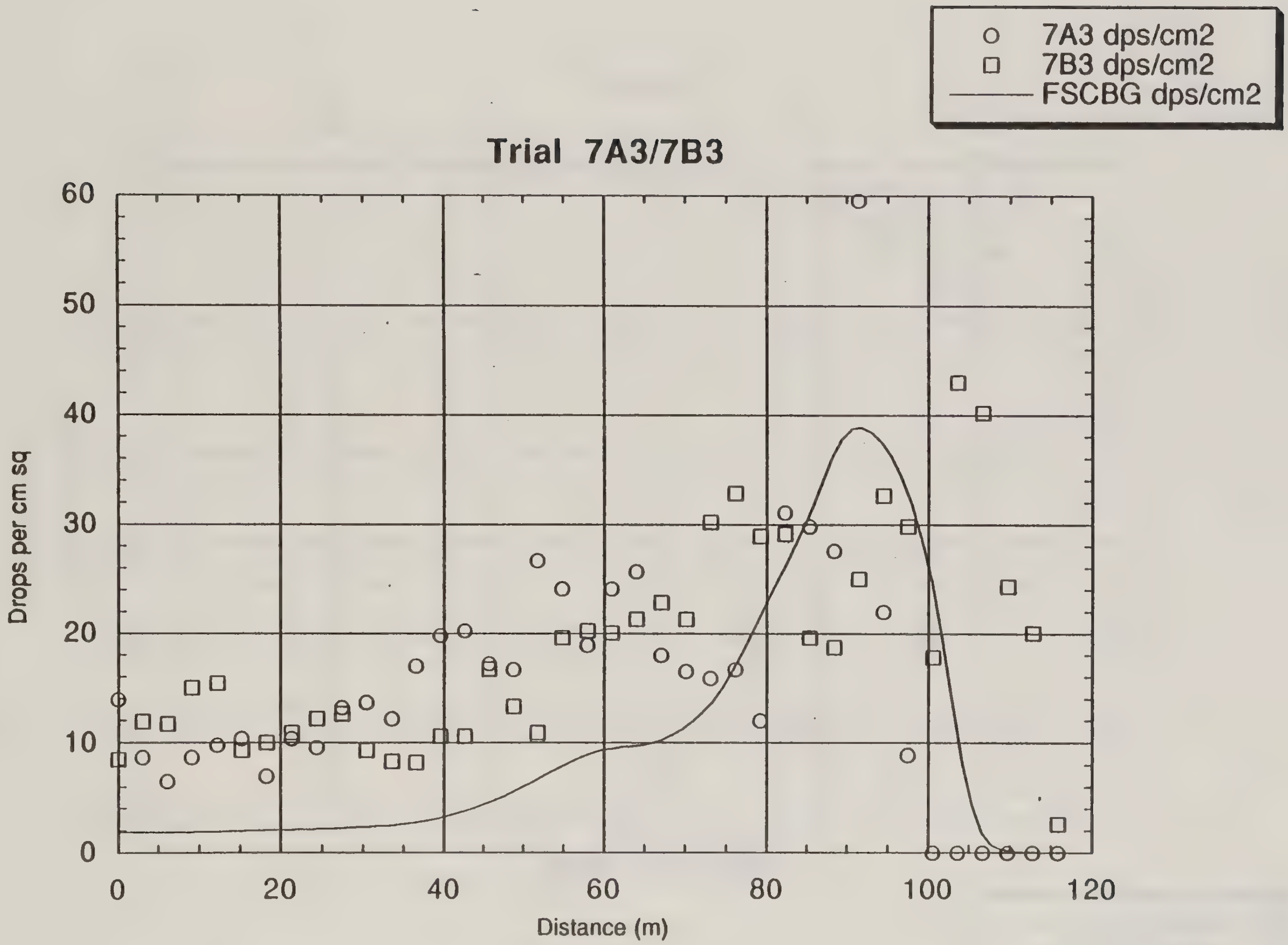
7A1 oz/ac
7B1 oz/ac
FSCBG oz/ac
Trial 7A1/7B1
500
400
300
200
100
0
Volume (oz/ac)
0
20
40
60
80
100
120
Distance (m)



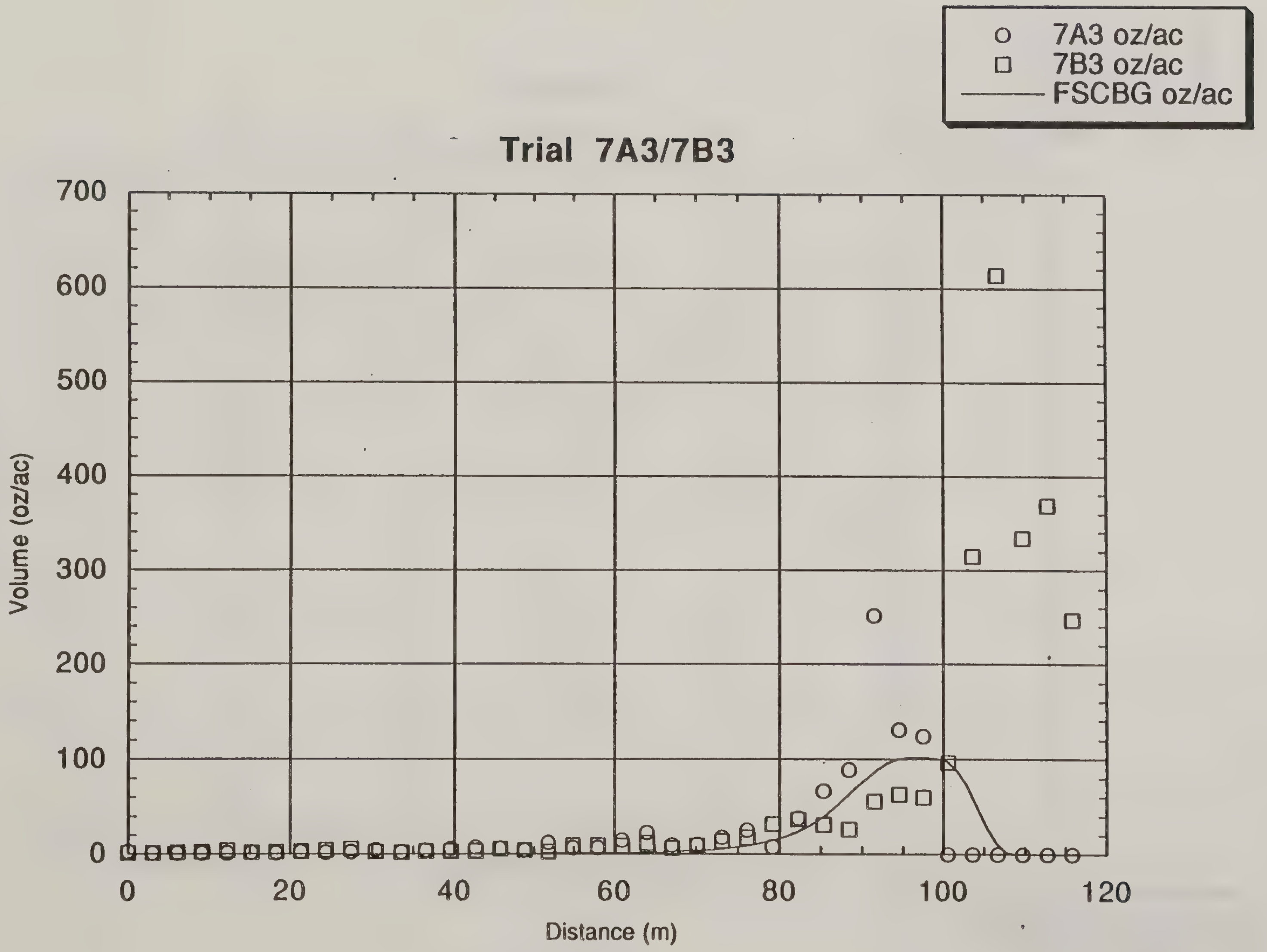
Trial 7A2/7B2
7A2 dps/cm2
7B2 dps/cm2
FSCBG dps/cm2
Drops per cm sq
Distance (m)
0
10
20
30
40
50
60
0
20
40
60
80
100
120

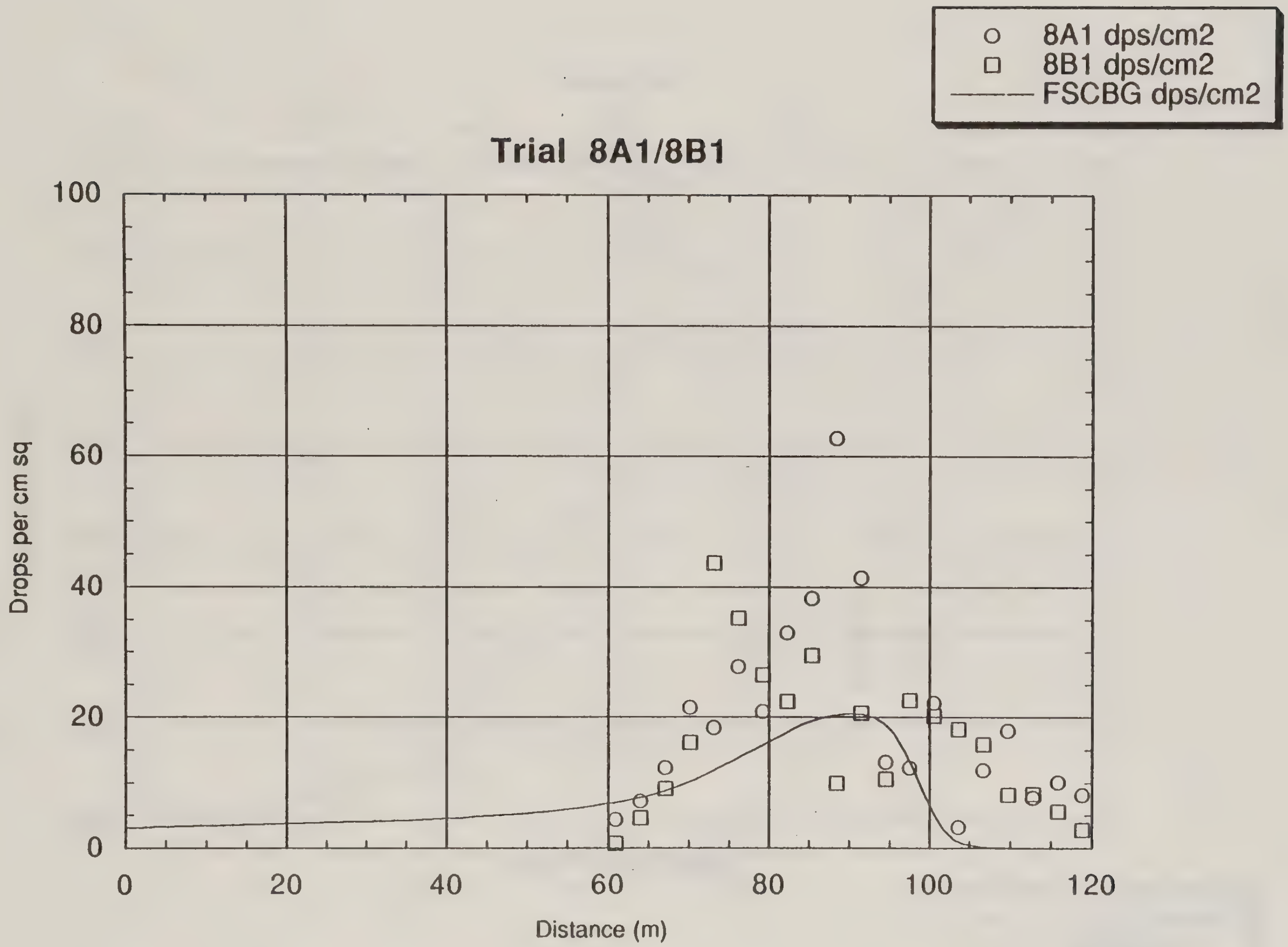


7A2 oz/ac
7B2 oz/ac
FSCBG oz/ac
Trial 7A2/7B2
500
400
300
200
100
0
Volume (oz/ac)
0
20
40
60
80
100
120
Distance (m)

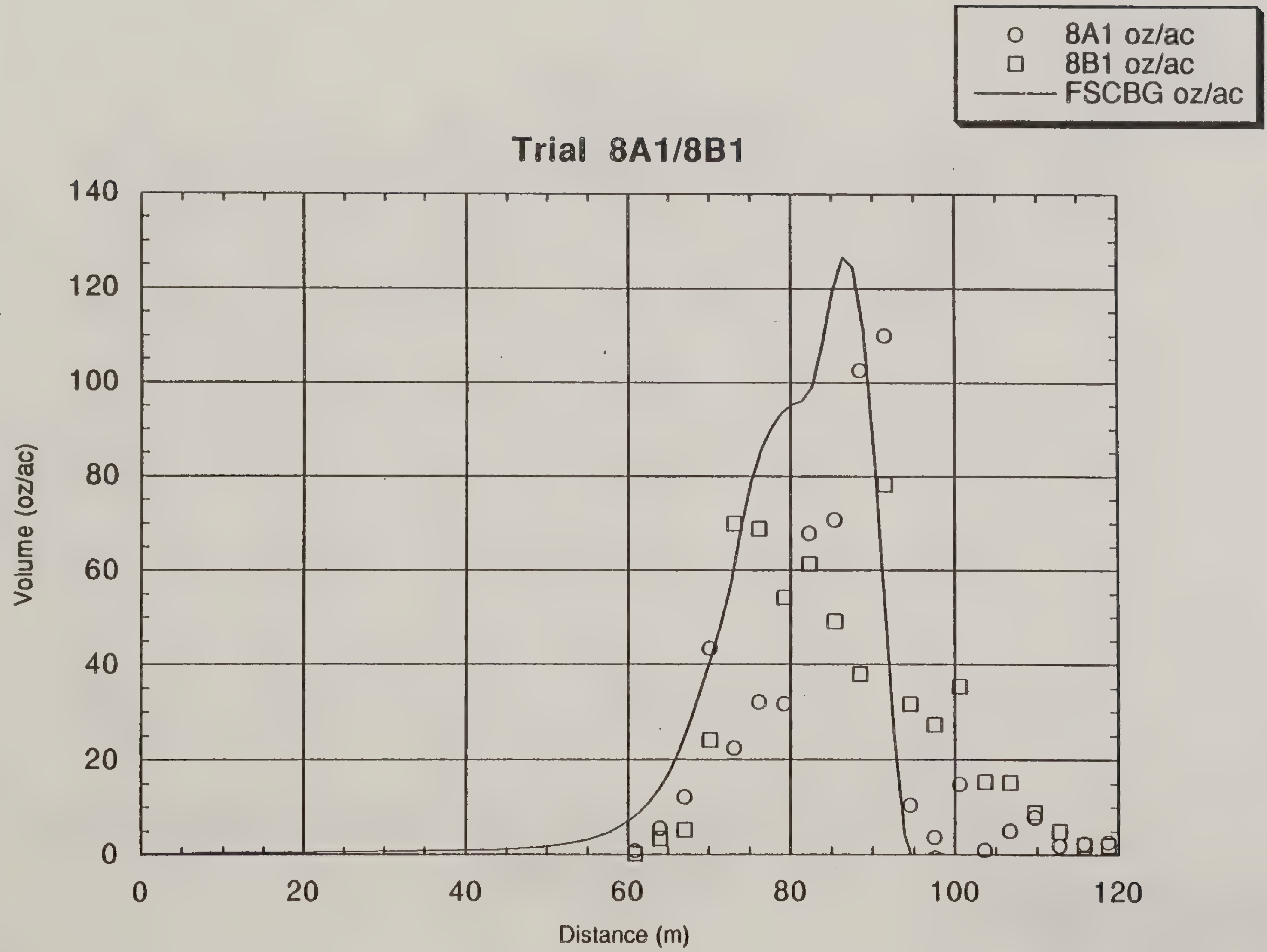


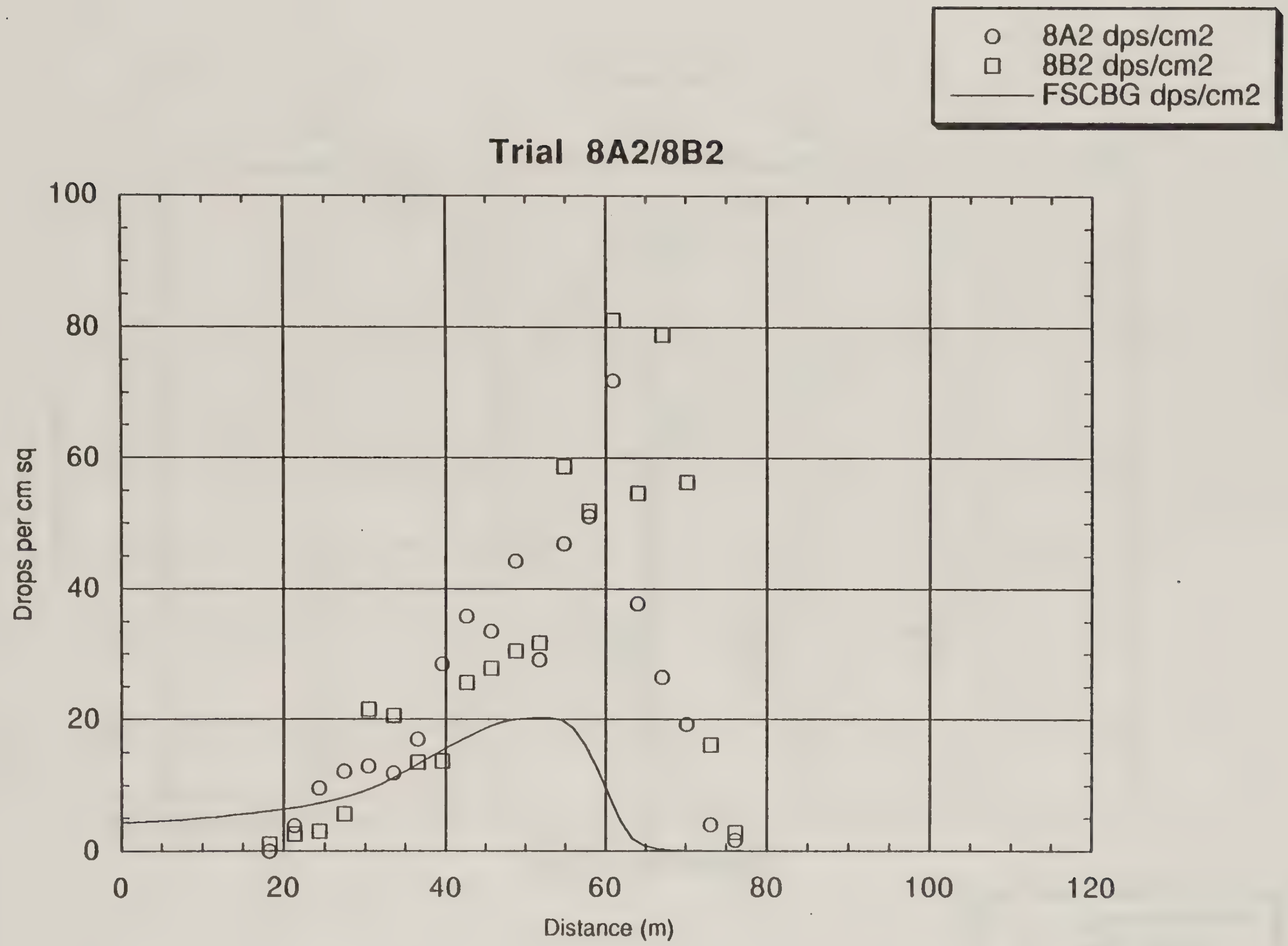
7A3 dps/cm2
7B3 dps/cm2
FSCBG dps/cm2
Trial 7A3/7B3
Drops per cm sq
Distance (m)
0
10
20
30
40
50
60
0
20
40
60
80
100
120


7A3 oz/ac
7B3 oz/ac
FSCBG oz/ac
Trial 7A3/7B3
Volume (oz/ac)
0
100
200
300
400
500
600
700
0
20
40
60
80
100
120
Distance (m)

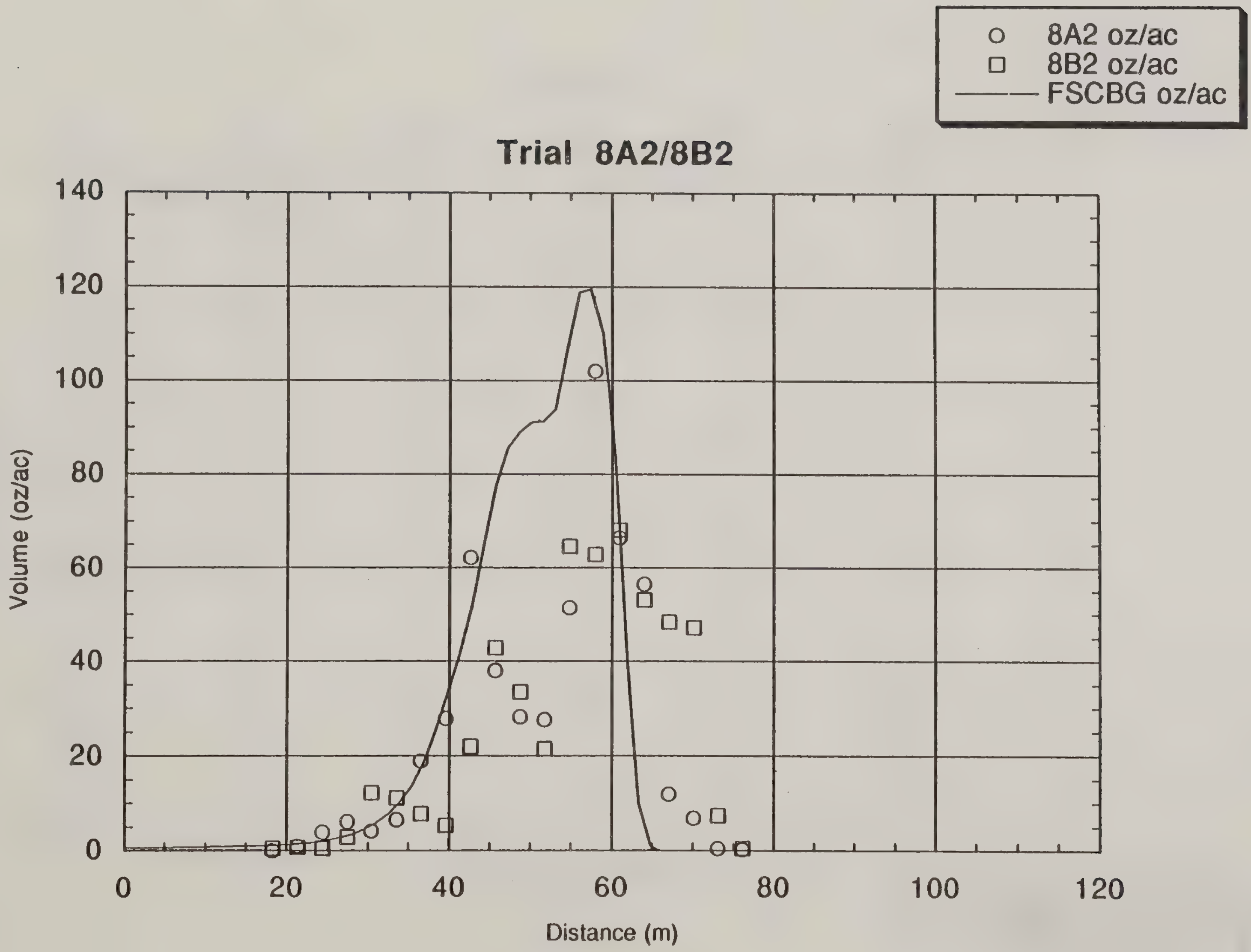


8A1 dps/cm2
8B1 dps/cm2
FSCBG dps/cm2
Trial 8A1/8B1
Drops per cm sq
100
80
60
40
20
0
0
20
40
60
80
100
120
Distance (m)

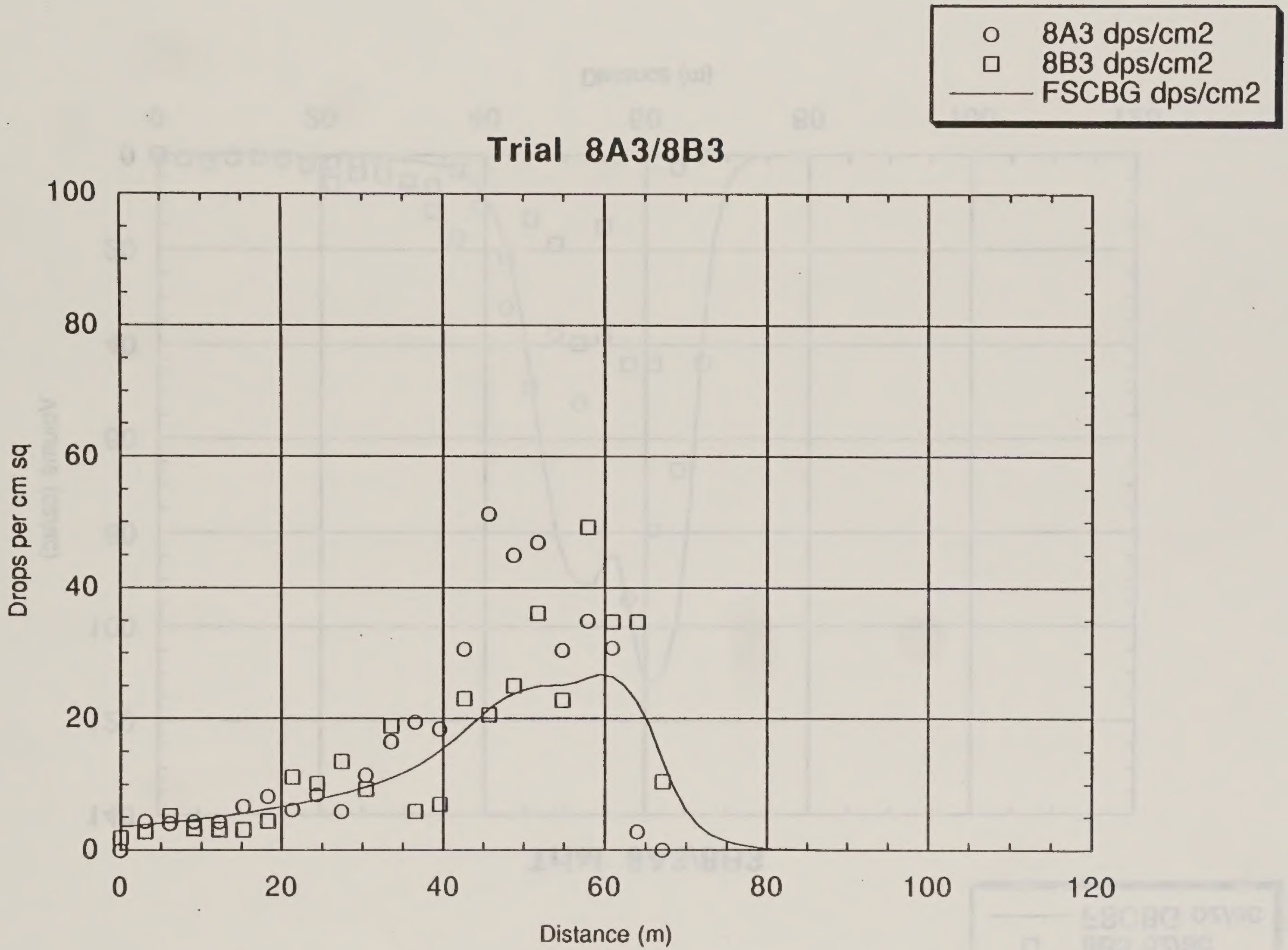

8A1 oz/ac
8B1 oz/ac
FSCBG oz/ac
Trial 8A1/8B1
140
120
100
80
60
40
20
0
Volume (oz/ac)
0
20
40
60
80
100
120
Distance (m)



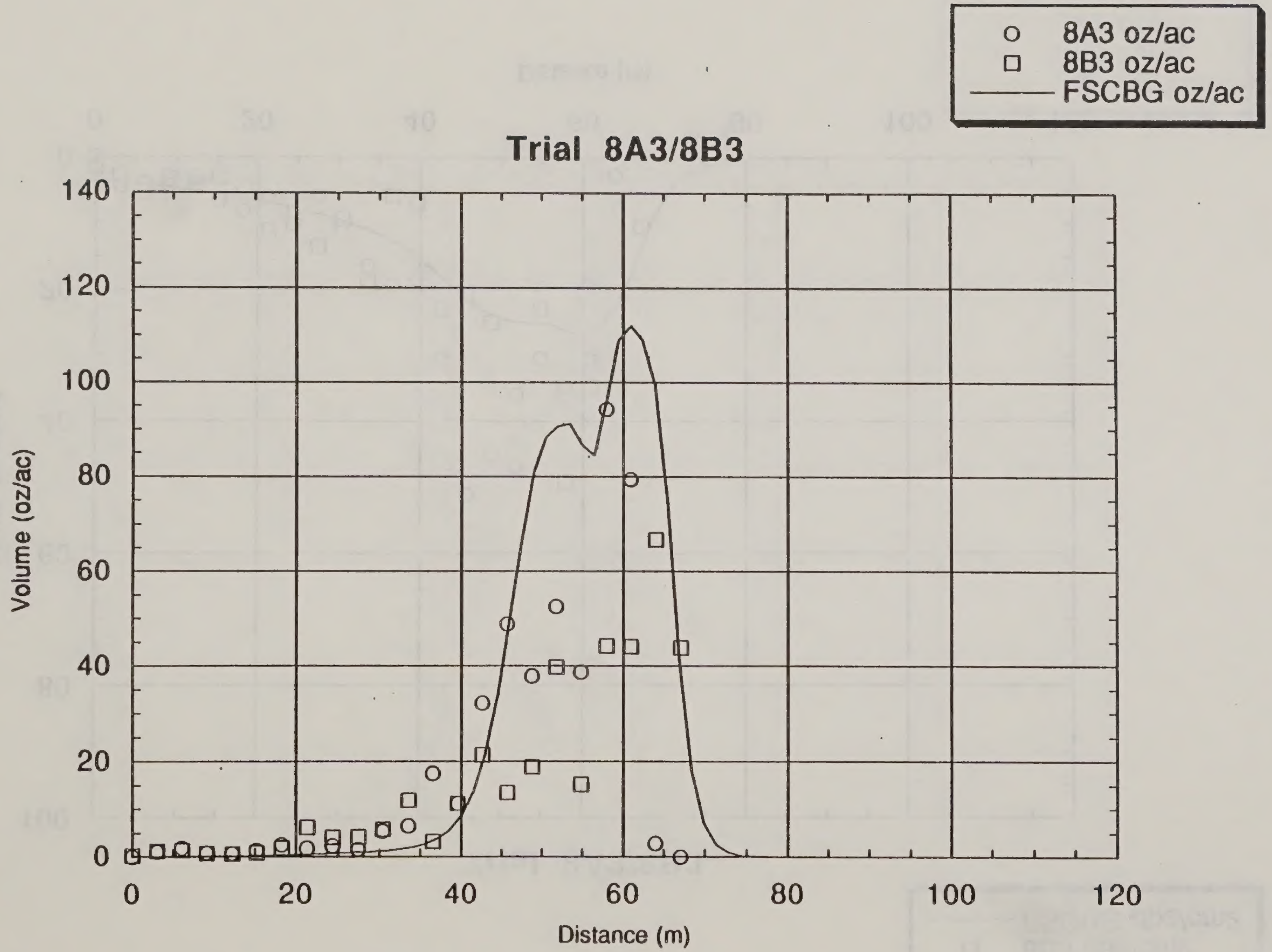
8A2 dps/cm2
8B2 dps/cm2
FSCBG dps/cm2
Trial 8A2/8B2
100
80
60
40
20
0
Drops per cm sq
0
20
40
60
80
100
120
Distance (m)



8A2 oz/ac
8B2 oz/ac
FSCBG oz/ac
Trial 8A2/8B2
Volume (oz/ac)
0
20
40
60
80
100
120
140
Distance (m)
0
20
40
60
80
100
120



Trial 8A3/8B3
8A3 dps/cm2
8B3 dps/cm2
FSCBG dps/cm2
Drops per cm sq
Distance (m)
0
20
40
60
80
100
120


Trial 8A3/8B3
8A3 oz/ac
8B3 oz/ac
FSCBG oz/ac
Volume (oz/ac)
Distance (m)
0
20
40
60
80
100
120
140